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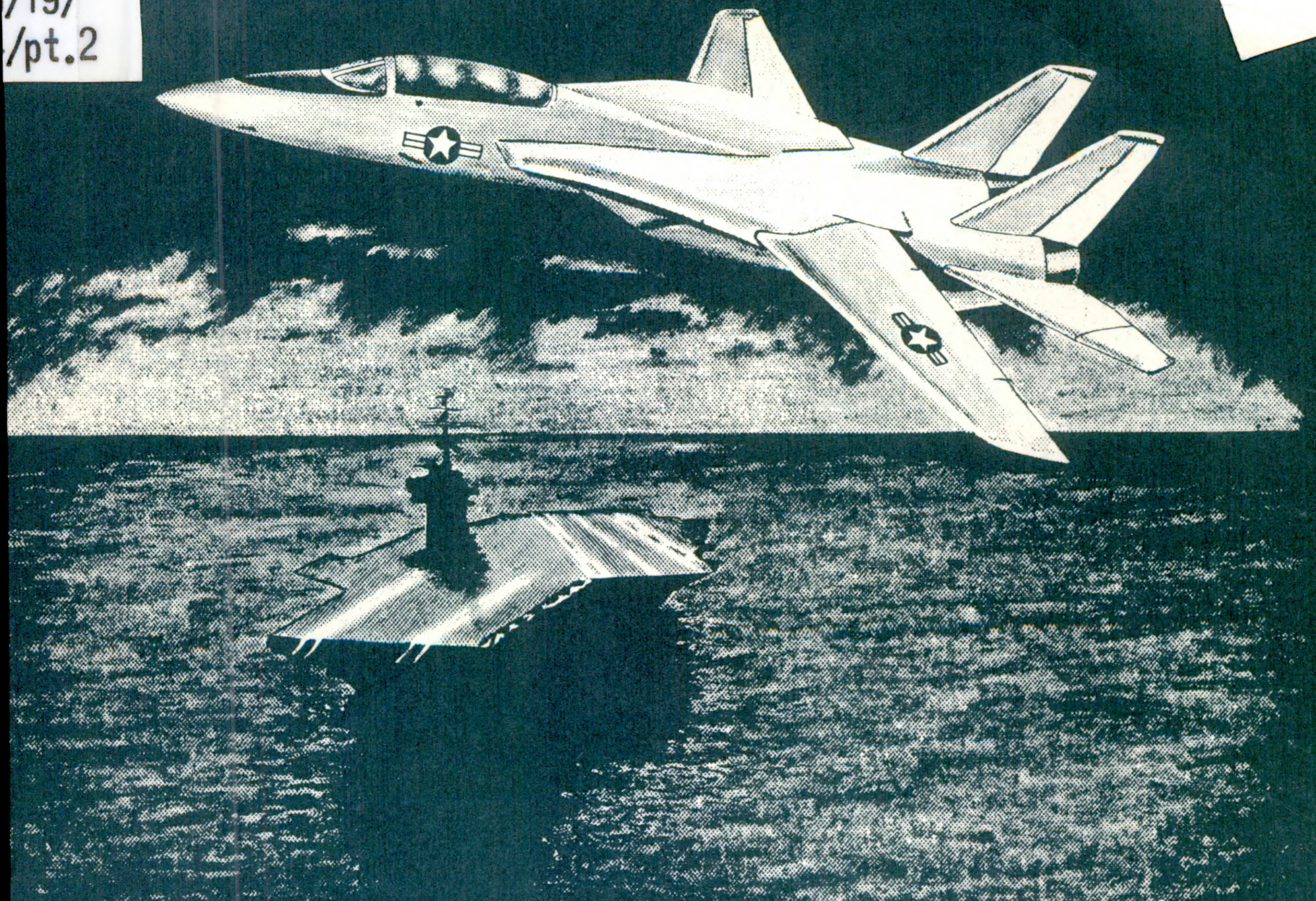

AVIATION
FIRE CONTROL TECHNICIAN 3 & 2, PART 2

DEPOSITORY
JUL 26 1984
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

NAVAL EDUCATION AND TRAINING COMMAND
RATE TRAINING MANUAL AND NONRESIDENT CAREER COURSE

NAVEDTRA 10387-D

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STACKS

Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading *Aviation Fire Control Technician 3 & 2*, Part 2, NAVEDTRA 10387-D.

Naval Education And Training Program Development Center

AVIATION FIRE CONTROL TECHNICIAN 3&2, PART 2

NAVEDTRA 10387-D

DEPARTMENT OF THE NAVY ★ CHIEF OF NAVAL EDUC AND TNG ★

1984 Edition Prepared by
AQCS Johnny R. Reeves

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PREFACE

This rate training manual and nonresident career course (RTM/NRCC) forms a self-study package that will enable Aviation Fire Control Technicians to fulfill the requirements of their rating. Designed for individual study, the RTM provides subject matter that relates directly to the occupational standards for the AQ Third and Second Class. The NRCC includes learning objectives and supporting items designed to lead students through the RTM. The occupational standards used as minimum guidelines in the preparation of this manual are to be found in the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068-D.

This rate training manual was prepared by the Naval Education and Training Program Development Center, Pensacola, Florida, for the Chief of Naval Education and Training. Technical review of the manuscript was provided by personnel of the Naval Aviation Logistics Center, NAS Patuxent River, Maryland; Naval Air Station Cecil Field (NAMTD 1034), Jacksonville, Florida; Naval Air Station Miramar (NAMTD 1008), San Diego, California; Naval Air Station Whidbey Island (NAMTD 1001 and AIMD), Oak Harbor, Wahington; and Naval Air Technical Training Center, Naval Air Station Memphis, Millington, Tennessee.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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SUMMARY OF
AVIATION FIRE CONTROL TECHNICIAN 3 & 2

AVIONICS TECHNICIAN (AQ/AT/AX) 3 & 2, PART 1
NAVEDTRA 10319

Provides information on avionics related elementary physics, basic theory of analog and digital computers, radar principles, doppler navigation principles, infrared principles, aviation maintenance practices and related safety precautions, avionics test equipment, forms applicable to the Naval Aviation Maintenance Program (NAMP), logistics support information, and security considerations applicable to the AQ, AT, and AX ratings.

AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

Provides fundamental information on the following subject matter areas: handtools and materials, servosystems, data sensing elements, weapon control fundamentals, the bombing problem, radar circuits, weapons control radar, principles of navigation, electro-optical sight systems, electrical power and ground cooling systems, television, and avionics maintenance.

CHAPTER 1

AVIATION FIRE CONTROL TECHNICIAN RATING

This training manual is Part 2 of a two-part series. It is designed as a self-study text for use by those personnel of the Navy and Naval Reserve preparing to meet the professional (technical) standards for advancement to Petty Officer Third Class and Petty Officer Second Class in the rating of Aviation Fire Control Technician. Also, this manual is used to improve job skills, and it is valuable as a source for job performance at the more senior rates.

The minimum requirements for each rate and rating are identified in the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068D. The occupational standards define the tasks required of, and within, each rate and rating. This rate training manual is based primarily on the professional standards for AQ3 and AQ2 as specified in the NAVPERS 18068. Keep in mind that changes in the occupational standards occurring after Change D of NAVPERS 18068 may not be reflected in this manual. A list of the occupational standards for AQ3 is presented in table 1-1. Table 1-2 shows the occupational standards for AQ2. Table 1-3 shows those occupational standards which are not covered in this manual, but which are covered in the *Avionics Technican (AQ/AT/AX) 3 & 2*, Part 1, NAVEDTRA 10319. Also included in tables 1 and 2 are the chapter(s) in which each occupational standard is covered.

Combined with the necessary practical experience, the completion of this manual will assist in the preparation for advancement. This training manual is a valuable source for job performance at the senior rates.

SCOPE OF THE AVIATION FIRE CONTROL TECHNICIAN RATING

The Aviation Fire Control Technician rating is included in the Navy Occupational Field 5 (Aviation Maintenance/Weapons). It is a general rating up to pay grade E-9. At pay grade E-9, the Aviation Fire Control Technician rating loses its identity. Personnel of pay grade E-8 in this rating, along with AECS, AXCS, and ATCS personnel, advance to Master Chief Avionics Technician (AVCM). Aviation Fire Control Technicians (AQs) inspect and perform organizational and intermediate maintenance on aircraft weapons systems, including weapons control radar, computers, computing sights, gyroscopes, accessories, related equipment, and air-launched guided missile equipment.

As an Aviation Fire Control Technician Third Class or Second Class, your assignment possibilities cover a wide range of duties and responsibilities. Your specific duties will depend, to a great extent upon the type of organization to which you are attached. More than likely, you will be assigned to billets concerning the maintenance of aircraft weapons systems and associated equipment. As an AQ, you may be attached to any one of several types of aircraft maintenance activities.

In the aircraft squadron, your duties are concerned primarily with the avionics division of the maintenance department. You work under the supervision of the avionics division chief on all routine maintenance and minor repair and perform such other duties as may be assigned by the avionics officer. In some squadrons, you may serve as plane captain.

Table 1-1.—Occupational Standards for Aviation Fire Control Technician Third Class

Number	Occupational Standard	Chapter
14	Electronics Maintenance	
14155	Test for short circuits, grounds, and continuity of interconnecting cables	13
14157	Test and repair or replace defective circuit parts	7
14158	Perform point-to-point voltage and resistance measurements	8
14159	Observe and compare voltage waveforms at circuit test points	8
14645	Isolate malfunctions to a line replaceable unit	8
14646	Perform operational ground checks	8
14767	Check and service liquid and air cooled avionics systems	8
14811	Remove and install units of avionics equipment	7
14812	Adjust power supplies	8
14830	Assist in troubleshooting fire/missile control radar systems	5 through 9
14832	Assist in troubleshooting and repair of analog and digital computers	5, 6
14833	Assist in troubleshooting and repair of fire/missile control optical systems	10
14834	Assist in troubleshooting and repair of fire/missile control gyro stabilizing systems and sensing elements	4, 9
14836	Assist in troubleshooting and repair of fire/missile control TV systems	12
15	Hydraulics Maintenance	
15327	Service fire/missile control systems hydraulics	13
28	Technical Drawings	
28059	Use schematics to trace and troubleshoot circuits	7
28060	Use system block diagrams and data flow charts to maintain avionics equipment	8, 9

Table 1-1.—Occupational Standards for Aviation Fire Control Technician Third Class—Continued

Number	Occupational Standard	Chapter
38	Administration	
38943	Assist in maintaining the following: A. Technical library B. Tool inventory C. Training records D. Test equipment inventory	2, 13
40	Fabrication and Manufacturing	
40524	Fabricate, replace, and repair interconnecting electronic cables	13
50	Maintenance Planning and Quality Assurance	
50941	Perform daily, preflight, postflight, turnaround and conditional inspections of aircraft	8
54	Logistic Support	
54665	Inventory and order tools and supplies	2
62	Aircraft Handling and Aviation Support	
62265	Prepare aircraft for ground maintenance and obtain necessary ground support equipment	11
92	Electro/Mechanical Maintenance	
92372	Assist in the boresighting of airborne fire/missile control systems	13
94	Mechanical Maintenance	
94424	Use and maintain hand tools	2
94614	Solder and splice electrical connections	2, 12
94773	Secure and safety wire, equipment and components	2

Table 1-2.—Occupational Standards for Aviation Fire Control Technician Second Class

Number	Occupational Standard	Chapter
14	Electronics Maintenance	
14174	Test and repair printed and transistor circuits	7
14755	Perform waveform analysis	13
14756	Perform phase, balance, and feedback adjustments to servo amplifiers	3, 13
14839	Troubleshoot and repair fire/missile control radar systems	5 through 9
14841	Troubleshoot and repair analog devices and digital data systems	5
14842	Troubleshoot and repair fire/missile control optical systems	10
14843	Troubleshoot and repair fire/missile control gyro stabilizing systems and sensing elements	4, 9
14845	Troubleshoot and repair fire/missile control TV systems	12
14847	Test and repair guided missiles and weapons	5, 6, and 13
38	Administration	
38798	Maintain test equipment calibration and tool records	2
51	Maintenance Planning and Quality Assurance	
51313	Perform debrief of flight crews	9
79	Corrosion Control and Material Preservation	
79282	Monitor avionics corrosion control	13
92	Electro/Mechanical Maintenance	
92040	Boresight weapons control system components	13
92356	Remove, install, align, and zero synchros	3

In the maintenance department of a naval air station or on an aircraft carrier, you may be assigned to an AIMD where you will perform intermediate maintenance on aircraft weapons systems components.

One of the shore duty billets available to you as an AQ2 may be assignment to the Naval Air Technical Training Center, Millington, Tennessee, as an instructor in the Avionics Technician School (Class A). In addition to the previously listed instructor billets, the AQ may be assigned to instructor duty with a Naval Air Maintenance Training Detachment (NAMTD). NAMTDs are located at shore stations on both coasts. Personnel

Table 1-3.—Occupational Standards for Aviation Fire Control Technician Second and Third Class found in the Avionics Technician 3 & 2, Part 1, (AZ/AT/AX)

Number	Occupational Standard
14831	Assist in troubleshooting and repair of fire/missile control radar systems
14835	Assist in troubleshooting and repair of fire/missile control laser systems
14837	Assist in troubleshooting and repair of fire/missile control data link
28375	Use maintenance and service instructions to maintain avionics sytems
46613	Use publications and maintenance information retrieval system to inspect, service, and maintain aircraft
40524	Fabricate, replace, and repair interconnecting electronic cables
50303	Use maintenance requirement cards (MRCs)
50694	Perform maintenance requirement inspections
50701	Comply with foreign object damage (FOD) program
50983	Complete maintenance data forms for: A. Completed maintenance actions (MAF) B. Work requests C. Unsatisfactory reports (UR) D. Support Action Forms (SAFs) E. Technical Directive Compliance (TDC)
79027	Inspect for and report corrosion
79264	Remove corrosion
79265	Apply corrosion preventive compounds
79080	Replace and service air filters and desicants
92082	Inspect and replace electrical circuit protective devices
92083	Inspect and maintain pressurize equipment
92351	Clean and lubricate avionics equipment
14757	Perform modifications to avionics equipment
14814	Diagnose reported discrepancies
14840	Troubleshoot and repair fire/missile control infrared systems
14844	Troubleshoot and repair fire/missile control laser systems
14846	Troubleshoot and repair airborne fire/missile control data link systems
18115	Use and perform routine upkeep of test equipment
38944	Maintain shop technical library
51114	Complete planned maintenance subsystem (PMS) feedback reports
51244	Perform collateral duty inspections
51313	Perform debrief of flight crews
51314	Interpret technical directives
41416	Maintain a visual information display system (VIDS)

assigned to this duty are first sent to the Instructor Basic Course, under the coordination of Naval Air Maintenance Training Group headquarters at Millington, Tennessee, for a period of indoctrination and instruction.

Instructor billets are normally filled on a voluntary basis. Detailed information concerning assignment to instructor duty is contained in the *Enlisted Transfer Manual*, NAVPERS 15909 (Series).

PERSONNEL ADVANCEMENT REQUIREMENT (PAR) PROGRAM

The *Personnel Advancement Requirement* (PAR) (NAVPERS 1414/4) was designed to be realistic in approach and operation. It allows a command to evaluate the overall abilities of an individual in a day-to-day work situation, eliminating the need to complete a mandatory, lengthy, and detailed check-off list.

E-3s, E-8s, and E-9s are exempt from the PAR program. E-3 apprenticeships are broad, making the development of a single PAR impractical. E-8s and E-9s are exempt from the PAR program since there are other means of selection for advancement to these pay grades.

Each rating PAR lists the requirements for advancement to pay grades E-4 through E-7 in one pamphlet. Each PAR contains descriptive information, instructions for administration, special rating requirements (such as physical, citizenship, security clearance requirements), and advancement requirements in the following sections:

Section I—Administration Requirements.

Section II—Formal School and Training Requirements.

Section III—Occupational and Military Requirements.

Section I (Administration Requirements) contains the individual's length of service, time in rate, and a check off for the individual that has passed the E-4/E-5 Military Leadership Examination.

Section II (Formal Schools and Training) contains a check-off entry for the individual that has completed the applicable military requirements rate training manual and the rate training manual (RTM) for the individual rating.

Section III (Occupational and Military Ability) is a check-off list of task statements. Items in this section are to be interpreted broadly and do not demand actual demonstration of the item or completion of the alternate local examination, although demonstration is a command prerogative. Individuals are evaluated on their ability to perform the task, whether evaluation is by observation of ability in related areas, training received, or, if desired, by demonstration.

There is currently a pilot program which includes the PQS (discussed in the next section) watch station qualifications and preventive maintenance actions as a separate section of the PAR form. Section III (Occupational and Military Abilities) under this program lists those task statements required of the rating which are not reflected in the PQS requirements. As PQS are developed, and if the pilot program is accepted, PAR forms will be revised to reflect the PQS requirements.

PAR forms are stocked in the Navy Supply System and are listed in the *Navy Stock List of Publications and Forms*, Section I, NAVSUP Publication 2002.

PERSONNEL QUALIFICATION STANDARDS (PQS)

Personnel Qualification Standards (PQS), described in OPNAV Instruction 3500.34, are presently being used to provide guidelines in preparing for advancement and qualifications for operating specific equipment and systems. They are designed to support the advancement requirements as stated in the occupational standards manual. A general description of the PQS is presented in the following paragraphs.

The occupational standards are stated in broad terms. Each PQS is more specific in its questions that lead to each qualification. It provides an analysis of specific equipment and duties, assignments, or responsibilities which an individual or group of individuals (within the same rating) may be called upon to carry out. In other words, each PQS provides an analysis of the complete knowledge and skills required of that rating tied to a specific weapon system (aircraft and/or individual systems or components).

Each qualification standard has four main subdivisions in addition to an introduction and a glossary of PQS terms. They are as follows:

100 Series—Theory.
200 Series—System.
300 Series—Watch stations (duties, assignments, or responsibilities).
400 Series—Qualification cards.

The introduction explains the complete use of the qualification standard in terms of what it will mean to the user as well as how to use it.

The Theory (100 Series) section specifies the background theory required as a prerequisite to the commencement of study in the specific equipment or system for which the PQS was written. These fundamentals are normally taught in the formal school (for example, Class A School) phase of an individual's training. However, if the individual has not been to school, the requirements are outlined and referenced to provide guidelines for a self-study program.

The Systems (200 Series) section breaks down the equipment or systems to be studied into functional sections. PQS items are essentially questions asked in clear, concise statement (question) form and arranged in a standard format. The answers to the questions must be extracted from the various maintenance manuals covering the equipment of systems for which the PQS is written. This section asks the user to explain the function of the system, to draw a simplified version of the system from memory, and to use this drawn schematic or the schematic provided in the maintenance manual while studying the system or equipment. Emphasis is given to such areas as maintenance management procedures, components, component parts, principles of operation, system interrelation, numerical values considered necessary to operation and maintenance, and safety precautions.

The Watch station (300 Series) section includes questions about the procedures the individual must know to operate and maintain the equipment or system. A study of the items in the 200-Series section provides the individual with the required information concerning what the system or equipment does, how it does it, and other pertinent aspects of operation. In the 300-Series section, the questions advance the qualification process by requiring answers or demonstrations of ability to put this knowledge to use or to cope with maintenance of the system or equipment. Areas covered include normal operation; abnormal or emergency operation; emergency procedures which could limit damage and/or casualties associated with a particular operation; operations that occur too infrequently to be considered mandatory performance items; and maintenance procedures/instructions such as checks, tests, repair, or replacement.

The 400-Series section consists of the qualification cards. These cards are the accounting documents utilized to record the individual's satisfactory completion of items necessary to becoming qualified in duties assigned. The place to start completing a standard will depend on the individual's assignment within an activity. A complete PQS should be given to each person being qualified so that each individual can utilize it at every opportunity to become fully qualified in all areas of the appropriate rating and the equipment or system for which the PQS was written. Upon transfer to a different activity, each individual must requalify. The answers to the questions asked in the qualification standards may be given orally or in writing. They are given to the supervisor, the branch or division officer, and/or maintenance officer as required to certify proper qualification. The completion of part or all of the PQS provides a basis for the supervising petty officer and officer to certify completion of personnel advancement requirements.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects relating to the military requirements for advancement and the professional qualifications of your rating.

Some of the publications listed here are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, you should be sure you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you to do your work or to advance. Rather, you are likely to waste time and study misleading information.

Several publications that you will need to study or to refer to are listed in this chapter. You may find it useful to consult some of the rate training manuals prepared for other aviation ratings as a reference. These training manuals will add to your knowledge of the duties of other personnel in the field of aviation. The manuals listed below are basic manuals.

Navy Electricity and Electronics Training Series (NEETS), Modules 1 through 5, 13, and 15.

Avionics Technician (AQ/AT/AX) 3 & 2, (Part 1), NAVEDTRA 10319

Basic Electronics, Volume 1, NAVPERS 10087-C

Basic Electronics, Volume 2, NAVEDTRA 10087-C1

Installation Practices, Aircraft Electric and Electronics Wiring, NAVAIR 01-1A-505

Fluid Power, NAVPERS 16193-B (Chapters 4 and 13)

Tools and Their Uses, NAVPERS 10085-B (Chapters 1 and 3)

CHAPTER 2

HANDTOOLS AND MATERIALS

You now should have a more firm concept as to just what you will encounter as an Aviation Fire Control Technician. You know, to some extent, what your technical responsibilities will be and the types of duty to which you may be assigned. Let us now get into some of the nitty-gritty of being an Aviation Fire Control Technician by discussing some of the handtools and materials that you will encounter.

As a skilled technician, you will be identified by the way that you handle and care for your tools and materials. Tools are a costly investment and should be cared for and used to full advantage. There seems to be something about a good tool that helps the average technician turn out better than average work. This fact alone more than justifies the slightly higher cost of quality tools. Even more important is the fact that low quality tools become defective more readily, and can result in injury to the user, or damage to the equipment undergoing repair.

In the same manner, proper use of quality materials improves the quality of any maintenance task and reduces the possibility of new failures. It is your responsibility to become thoroughly familiar with the tools and materials of your trade and to be proficient in their care and use.

HANDTOOLS

For our discussion, the term "handtools" is used to refer to the small portable or fixed power tools commonly available in electronics maintenance shops, or used by electronics maintenance personnel during work on aircraft, as well as those normally classified as nonpowered handtools.

SAFETY, USE AND CARE OF HANDTOOLS

Carelessness is the greatest menace in any shop. It must come from the technician; the machine alone cannot inflict injury. Lack of care is the cause of most accidents in electrical and electronics shops today. It should be remembered that all moving machinery is potentially dangerous. It is unsafe to lean against any machine that is in motion, or that may be started in motion by anyone else. Treat a machine with businesslike respect and there is no need to fear it. Do not start a machine until its operation and safety precautions have been fully explained to you by a competent instructor.

Chapter 7 of *Avionics Technician 3 & 2* (Part 1), NAVEDTRA 10319 (Series) contains some information concerning accident prevention involving machinery and tools that you should refer to frequently. Other excellent sources of information regarding handtools and their use and care are, *Airman*, NAVEDTRA 10307 (Series), and *Tools and Their Uses*, NAVEDTRA 10085 (Series). Since these manuals are basic to all aviation ratings, the material covered in them is not duplicated in our discussion. If you have not done so, you should review this material before proceeding with this manual.

Safety, relative to the use of tools, cannot be overemphasized. The following two safety precautions are basic to just about all use-of-tool situations.

1. Use the proper tool for its designed function, and use it in the proper manner.

2. Maintain all tools in proper working order and in a safe condition. Sharpen or replace dulled cutting tools, replace broken or defective tools, and protect tools from damage while in use or in storage.

When performing any function requiring the use of tools and/or materials, arrange them so that they are easily accessible but are not in a position to interfere with the work. This arrangement increases efficiency as well as safety.

Tools should be inventoried, cleaned, and inspected after the job has been completed. Return all tools to their proper storage place.

GENERAL TOOLS

Although the previously mentioned basic manuals provide many details regarding common general tools, a few additional comments are of importance. The comments are primarily of the "do" or "don't" type.

Never use a center punch on extremely hard metals or to remove bolts by force; to do so will dull the point. Never use a pin punch as a starting punch; a hard blow may cause the slim shank to break. Always use the largest starting and pin punch that will fit the hole. When using punches, do not strike a glancing blow; the punch may break, and broken pin punches are difficult to remove.

Do not hammer on a screwdriver. If an obstruction is in the slot, apply a driving force with the heel of the hand or remove the obstruction with a file. Never use a screwdriver as a pry bar, lever, or chisel. Do not use pliers or wrenches on a screwdriver to increase torque.

When using a grinding wheel, ensure the guard is in place. If it is necessary to use the wheel with the guard removed, stand to one side to avoid flying particles of emery or metal. Use safety goggles when using a grinding wheel to grind screwdriver blades or any metal object. Use the rest stand when possible, but ensure that the rest is close to the grinding wheel.

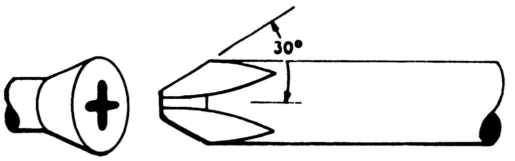
!WARNING!

NEVER use the grinding wheel on nonferrous metals. When used with this type of material, the grinding wheel could, in effect, explode. This could result in serious injury to or death of personnel.

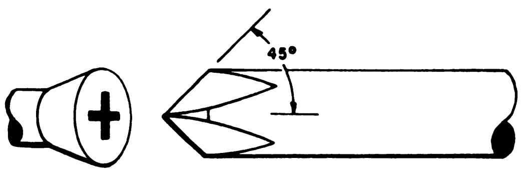
When drilling, never use the hand to hold the work being drilled. Use a vise or a clamp. The same idea applies to work being soldered, filed, or sawed.

Using a Reed and Price screwdriver when working on Phillips screws (or vice versa) can result in a ruined tool. Also, using the wrong screwdriver may round out the screwhead, making it difficult to remove the screw. Because of the difference in design of the two screws, the screwdrivers should not be used interchangeably. In general, Reed and Prince screws are used for airframe structural applications, while Phillips screws are found most often in component assemblies.

Figure 2-1 shows the difference between the two. The Phillips screwdriver has flukes that are approximately 30 degrees with a blunt end, while the Reed and Prince has 45-degree flukes and a sharper, pointed end. The Phillips screw has beveled walls between the slots, while the Reed and Prince has straight, pointed walls. In addition, the Phillips screw is not as deep as the Reed and Prince.



(A) PHILLIPS



(B) REED AND PRINCE

222.283

Figure 2-1.—Matching cross-slot screws and drivers.

Ways to identify the right screwdriver are as follows:

1. If it tends to stand up unassisted when the point is put in the head of a vertical screw, it is probably the proper one.
2. The outline of the end of a Reed and Prince screwdriver is approximately a right angle, as seen in the illustration.
3. The best thing is to know the descriptions of both types.

Using the right tool saves time and trouble, and is good maintenance practice.

SPECIAL TOOLS

You will, no doubt, use many tools which are not covered in the previously mentioned basic manuals. A wide variety of special tools are furnished by the manufacturers of the aircraft, engines, and related equipment. These tools are listed in special allowance lists and their use is explained in the maintenance or service instructions manuals covering the specific aircraft, engine, or item of equipment for which they were designed. Other tools are peculiar to the maintenance of electronic equipment, or have been developed since the basic manuals have been issued.

Although the following discussion is not complete, it is representative of the special tools most commonly used in aircraft electronics maintenance work.

NONMAGNETIC TOOLS

Tools made of nonmagnetic materials are available through normal supply channels. They are used for performing specific maintenance functions on certain classes of equipment or components. These expensive tools are normally made of beryllium-copper or plastic, are not as rugged as steel tools, and are more easily damaged. If you restrict their use to the purpose for which they were intended, you will prolong their useful life and increase their usefulness when required.

In addition to possible damage of the tool itself, indiscriminate use of these tools could allow them to transfer foreign particles to locations where possible trouble could result. In either case, the results could be of considerable inconvenience to you.

Nonmagnetic tools should always be used in the vicinity of magnetrons and other components containing permanent magnets. Magnetic tools could be attracted with sufficient force to cause damage to the magnet or injury to the technician; or the tool could become magnetized and transfer this magnetic condition to undesirable places.

Nonmagnetic tools should also be used in tuning rf circuits which are susceptible to frequency change resulting from the introduction of new magnetic fields (or the distortion of the existing magnetic fields). Many are slug-tuned if circuits involve this potential trouble.

Good general maintenance practice involves wiping the tools before use and again after use. This is especially advisable in the case of nonmagnetic tools. A lint-free cloth dampened with a suitable cleaning solvent may be used for this purpose.

INSULATED TOOLS

Safety considerations require that you use insulated tools whenever the danger of electrical shock or short circuit exists. Many types of tools are available in insulated form directly through supply channels at little or no additional cost. These tools should be obtained and used whenever available. However, many types of insulated tools are not readily available (or are available only at considerable added expense). If essential, these tools should be procured or conventional tools may be modified. Insulated sleeving may be put on the handles of pliers and wrenches and on the shanks of screwdrivers. Tools modified in this manner should be used only for low voltage circuits because of the limitations of the insulating materials. For higher voltage uses, special insulating handles are available for many of the common types of tools.

In some instances, it is necessary to use tools which are made of insulating material, rather than merely having an insulating handle. In these instances, the tools should be requisitioned through normal supply channels, if possible. If they are not available through normal supply channels, they may be purchased on the open market.

TORQUE WRENCHES

There are times when, for engineering reasons, a definite pressure must be applied to a nut. In such cases a torque wrench must be used. The torque wrench is a precision tool consisting of a torque-indicating unit and an appropriate adapter or attachments. It is used to measure the amount of turning or twisting force applied to a nut, bolt, or screw.

The three most commonly used torque wrenches are the deflecting beam, dial indicating, and micrometer setting types (fig. 2-2). When the deflecting beam and the dial indicating torque wrenches are used, the torque is read visually on a dial or scale mounted on the handle of the wrench.

At present, the most accurate and reliable torque wrench is the micrometer setting type. The next most accurate and reliable is the dial indicating type. The least accurate and reliable is the deflecting beam type. The deflecting beam type should not be used unless it is absolutely necessary to do so. This is because of the high probability of operator induced error.

To use the micrometer setting type, unlock the grip and adjust the handle to the desired setting on the micrometer type scale, then relock the grip. Install the required socket or adapter to the square drive of the handle. Place the wrench assembly on the nut or bolt and pull in the desired direction with a smooth, steady motion. (A fast or jerky motion will result in an improperly torqued unit.) When the torque applied reaches the torque value which is indicated on the handle setting, the handle will automatically release or "break" and move freely for a short distance. The release and free travel is easily felt, so there is no doubt the torquing process is complete.

To assure getting the correct amount of torque on the fasteners, all torque handles must be tested at least once a month or more often if usage indicates it is necessary.

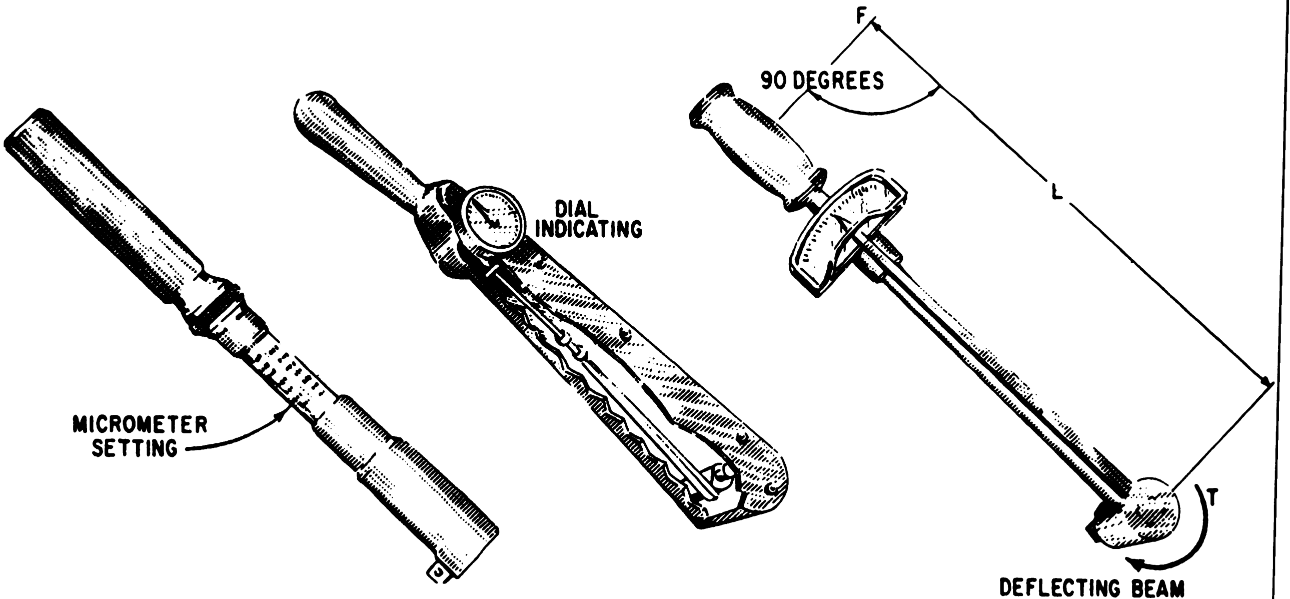


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Figure 2-2.—Torque wrenches.

You should observe the following precautions when using torque wrenches:

1. Always ensure proper calibration.
2. Do not use the torque wrench as a hammer.
3. When using the micrometer setting type, do not move the setting handle below the lowest torque setting. However, it should be placed at its lowest setting prior to returning to storage.
4. Do not use the torque wrench to apply greater amounts of torque than its rated capacity.
5. Do not use the torque wrench to break loose bolts which have been previously tightened.
6. Never store a torque wrench in a toolbox or in an area where it may be damaged.

RELAY TOOLS

Many relays have been damaged or ruined by the use of sandpaper or emery cloth to clean the contact points. Use of these abrasives causes bending of the contacts, and attempts to straighten them with longnose pliers causes further damage, eventually requiring replacement of the relays. This can be avoided by using a burnishing tool to clean dirty contact points. Figure 2-3(A) illustrates a burnishing tool being used on a relay.

Burnishing tools are stocked in supply activities and may be obtained through normal supply channels. Prior to using this tool, be sure to clean it thoroughly with alcohol, and then, do not touch the tool surface with the fingers prior to use.

Burned and pitted contacts cannot be repaired by burnishing. Such relays should be replaced.

Another tool useful in relay maintenance is a point bender (fig. 2-3 (B)), which is used to straighten bent relay contacts. It can be fabricated locally from 0.125-inch diameter rod stock shaped as indicated in the figure.

WIRE AND CABLE TOOLS

An innovation in electrical connectors is the taper pin electrical connector for aircraft. The taper pin works on the principle of driving a taper wedge into a tapered hole and depending on friction to retain the pin in the hole. The taper pin connector makes a very good electrical and mechanical connection because of the high metal to metal contact pressure developed during the

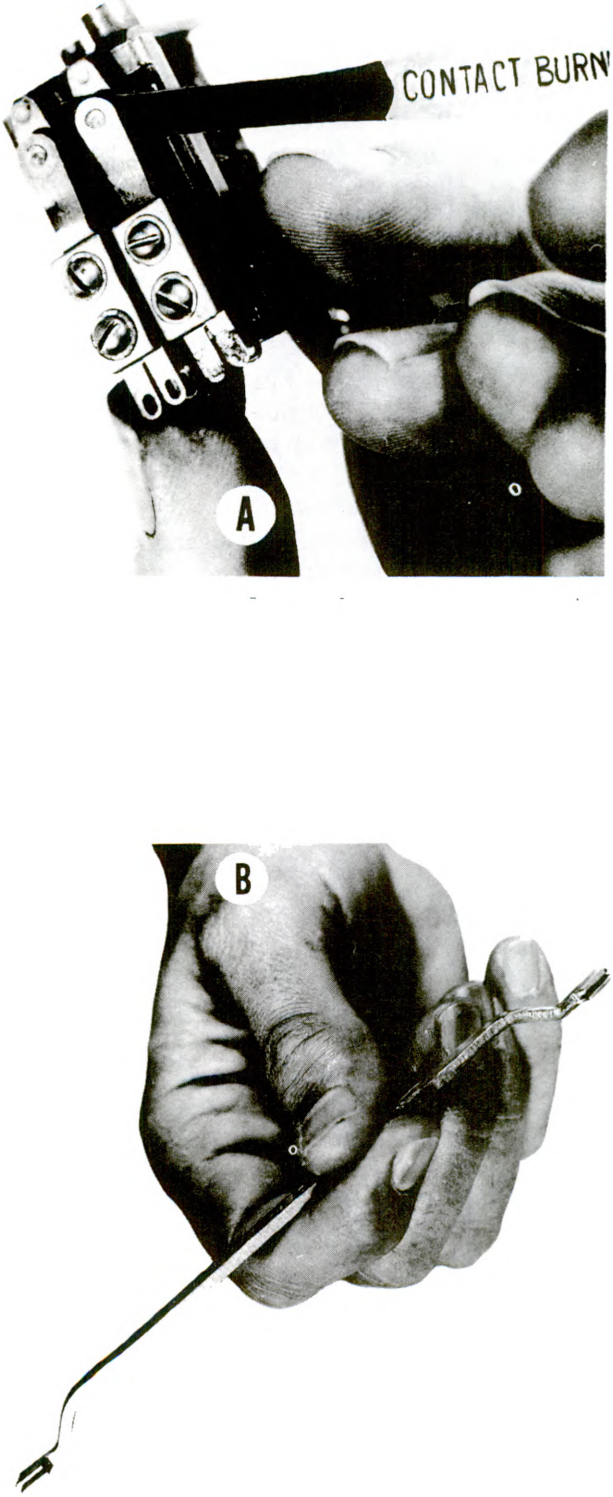

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Figure 2-3.—(A) Burnishing tool; (B) point bender.

driving action of the insertion tool. Taper pins permit circuit changes to be quickly and easily performed without a soldering iron. Tests show that vibration and corrosion, over a period of time, improve the electrical continuity and increase the mechanical pulling force required to remove a taper pin. Another advantage of taper pins is the accessibility of test points for voltage and circuit continuity checks.

Insertion and Removal

A special tool, shown in figure 2-4, is used to properly insert the taper pin into a terminal block socket. The insertion tool has a calibrated driving spring, a calibrated pull test spring, a taper pin captive key, and a taper pin removal feature.

The driving spring adjusts to apply the proper driving impact to the pin. The pull test spring adjusts to apply the correct pull force on the pin to check for proper pin insertion. The captive key ensures that each taper pin has a 100 percent pull test before the tool is disengaged from the pin. The removal lever is rotated to remove the taper pin from the terminal block socket.

In order to maintain the reliability of the system, it is imperative the taper pin be properly inserted into the terminal block sockets. Pushing the pins into the sockets with the fingers or pliers will not make them stay; they must be driven in with the insertion tool. The tool must be calibrated to ensure the proper pressures are used. When inserting the taper pins, the insertion tool must be held at right angles to the terminal block, and pushed straight toward the terminal block without twisting the tool. The pins are very sensitive to twists which could cause a faulty connection or a broken pin. Bent or broken pins should always be replaced. However, if correct installation procedures are followed, a taper pin may be installed and removed as many as 25 times before replacement is necessary. A properly installed taper pin will pass the pull test of the insertion tool.

Three different sizes of taper pins are used to terminate wires from sizes 16 through size 22. The sizes are identified by color coding of the insulating sleeves. A crimping tool is used to attach the taper pin to the wire. This taper pin crimping tool is similar to other types of wire

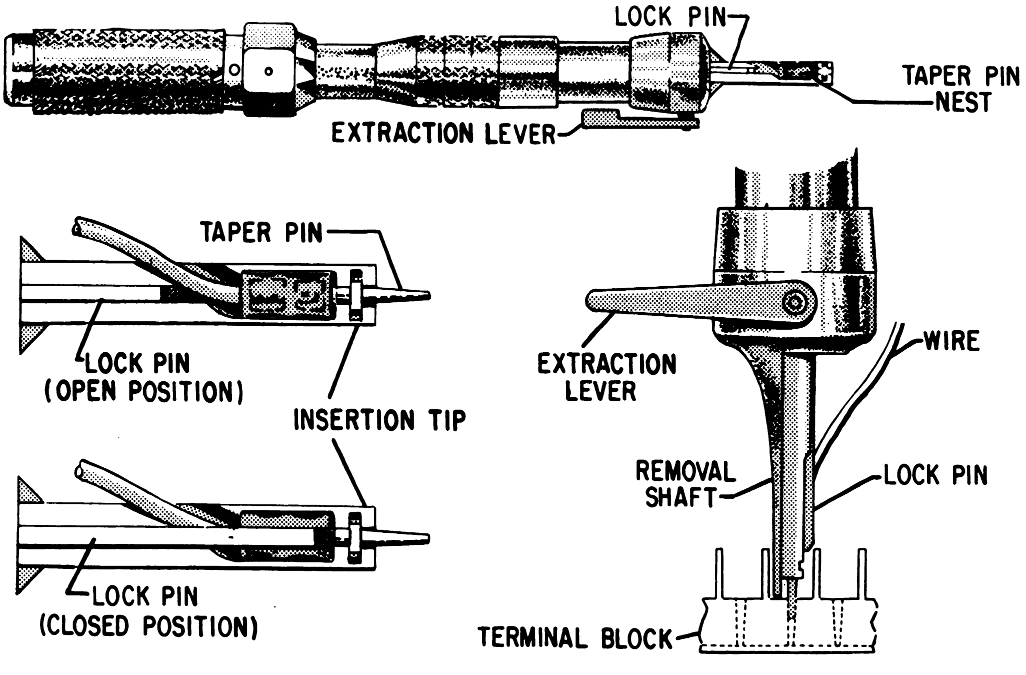

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Figure 2-4.—Taper pin insertion and removal tool.

terminal crimping tools, such as those discussed later in this chapter.

DIAGONAL PLIERS

Diagonal pliers are described briefly in *Tools and Their Uses*, NAVEDTRA 10087 (Series). The following discussion describes a modification which is advantageous when the diagonal pliers are used in the maintenance of equipment aboard aircraft where working clearances are likely to be close.

The diagonal pliers (fig. 2-5 (A)) have been modified by adding potting compound to the jaws. This prevents loss of small pieces of wire into the equipment when cutting wire. The potting compound also allows the technician to cut the wire without holding onto the piece being cut away. (Figure 2-5 (B) shows the diagonals before being modified.) If you do not have a pair of these modified diagonal pliers, manufacture your own by adding potting compound. Before applying the potting compound, clean the diagonals with solvent; then secure the handles with a rubber band (fig. 2-5 (C)) and apply the compound. Allow 24 hours for the compound to dry. The jaws may be separated by slicing them apart with a single edge razor blade.

SAFETY WIRING PLIERS

When installing equipment in aircraft, it becomes necessary to lockwire (usually referred to as safety wire) designated parts of the installation. The process of lockwiring can be accomplished faster and neater with the use of special pliers. However, the use of these pliers requires extreme care. The wire must be installed snugly, but not so tight that any part of the wire is overstressed. The routing of the twisted wire is prescribed by the particular installation, and in many instances is designated in the appropriate maintenance instructions manual.

Safety wiring pliers (fig. 2-6) are three-way pliers, which hold, twist, and cut. They are designed to reduce the time used in twisting safety wire on nuts and bolts. To operate, grasp the wire between the two diagonal jaws, and the thumb will bring the locking sleeve into place. A pull on the knob twirls the twister, making uniform twists in the wire. The spiral rod may be pushed

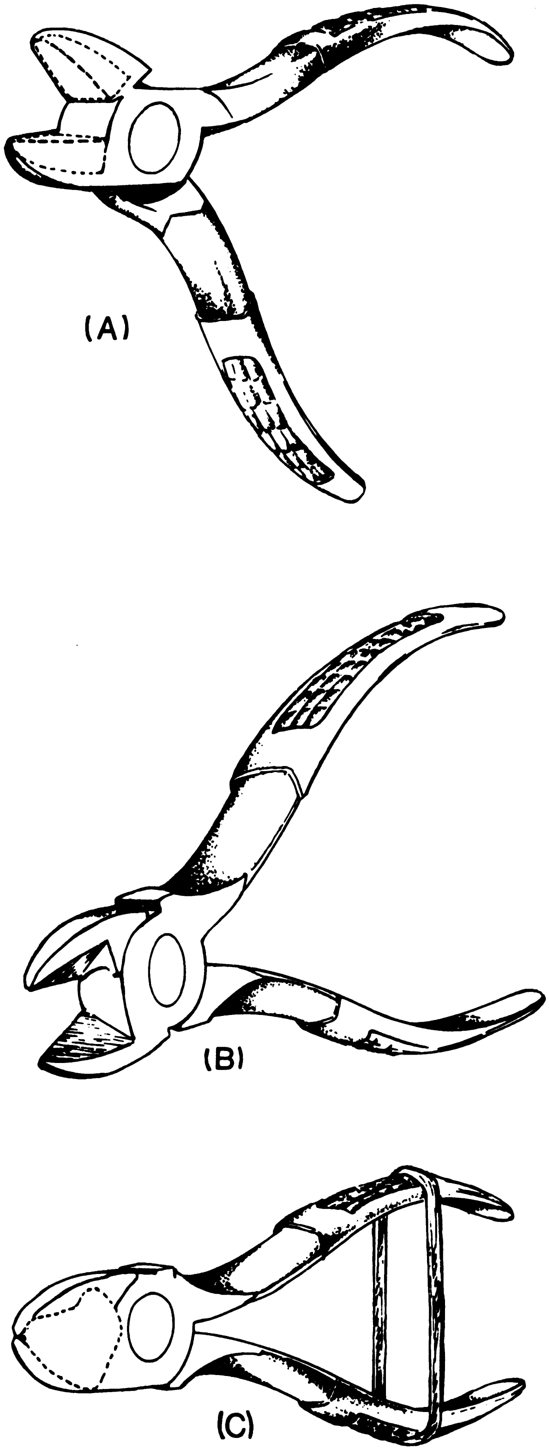

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Figure 2-5.—Diagonal pliers. (A) compound; (B) without compound; (C) apply compound.

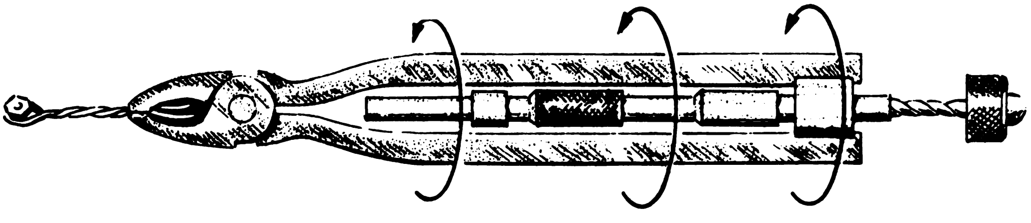

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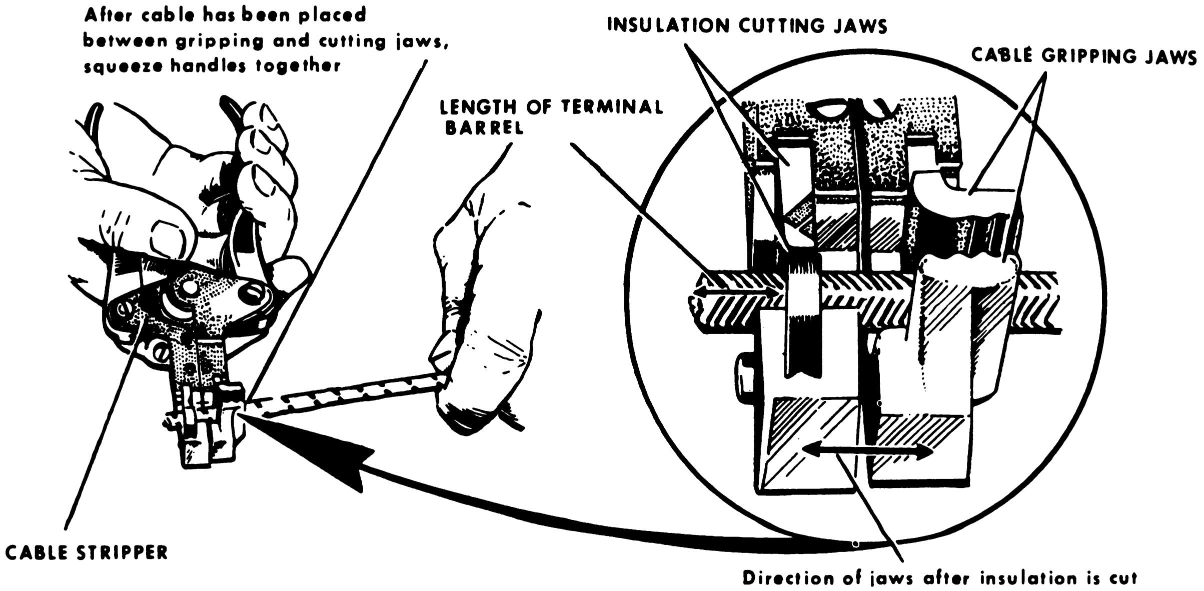
Figure 2-6.—Safety wiring pliers.


After cable has been placed between gripping and cutting jaws, squeeze handles together
INSULATION CUTTING JAWS
CABLE GRIPPING JAWS
LENGTH OF TERMINAL BARREL
CABLE STRIPPER
Direction of jaws after insulation is cut

243.278

Figure 2-7.—Wire and cable stripper.

back into the twister without unlocking it, and another pull on the knob will give a tighter twist to the wire. A squeeze on the handle unlocks the twister, and the wire can be cut to the desired length with the side cutter. The spiral of the twister should be lubricated occasionally.

WIRE AND CABLE STRIPPERS

Nearly all wire and cable used as electrical conductors are covered with some type of insulation. In order to make electrical connections with the wire, a part of this insulation must be removed, leaving the end of the wire bare. To facilitate the removal of this insulation, use a wire and cable stripping tool similar to the one shown in figure 2-7.

Although several variations of this basic tool are available, the most efficient and effective is the type illustrated. Its operation is extremely simple: Insert the end of the wire in the proper direction to the depth to be stripped, position the wire so it rests in the proper groove for that size wire, and squeeze. The tool functions in three steps as follows:

1. The cable gripping jaws close, clamping the insulated wire firmly in place. The wire must be inserted so the jaws clamp the main section of the wire rather than the end to be stripped.

2. The insulation cutting jaws close, cutting the insulation. If the wire is not inserted in a groove, the conductor will also be cut. If the wire is positioned into too small a groove, some of the strands will be severed. If the groove is too large, the insulation will not be completely severed. Inserted properly into the correct groove, the insulation will be cut neatly and completely, and the wire will not be damaged.

3. The two sets of jaws separate, removing the clipped insulation from the end of the wire.

CRIMPING TOOLS

Type MS 25037-1

The standard tool MS 25037-1, issued for crimping solderless terminals, is for use with standard insulated copper terminal lugs manufactured according to MS 25036. The standard tool employs a double jaw to hold the terminal lug or splice. One side of the jaw applies crimping action to fasten the terminal to the bare wire when the terminal is inserted, as shown at the left in figure 2-8.

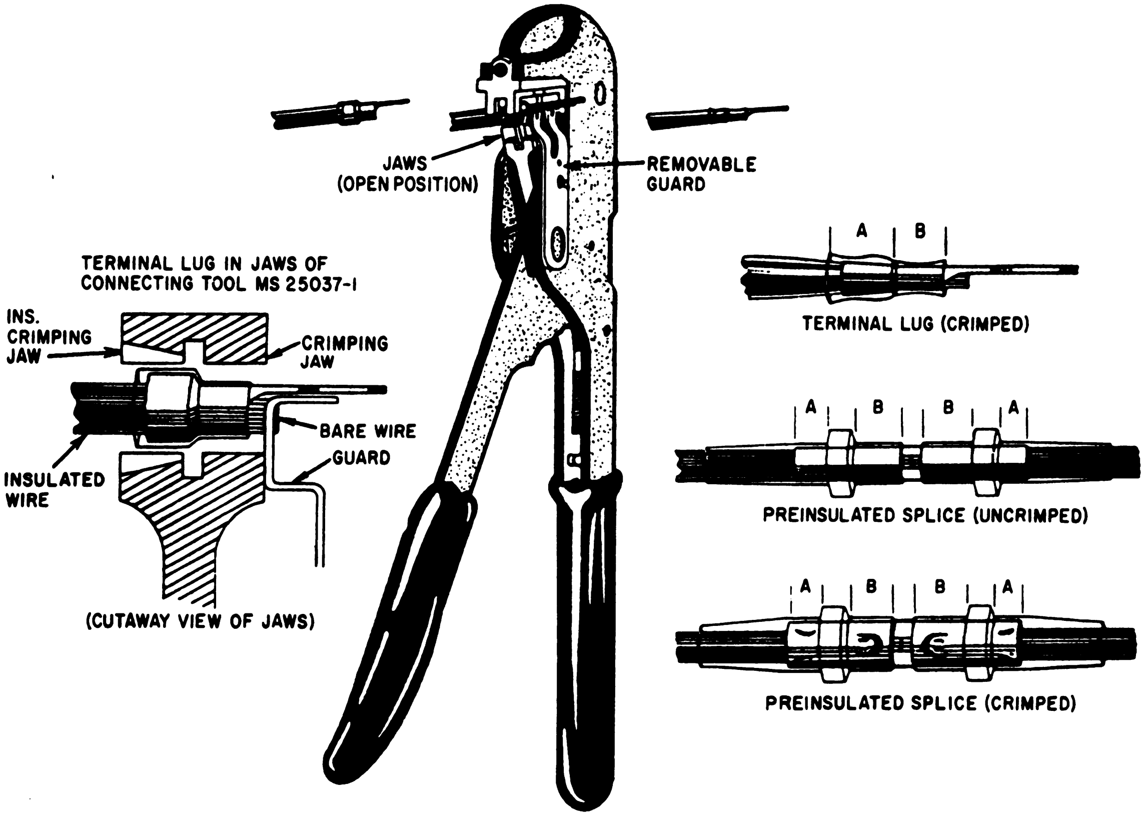


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Figure 2-8.—Crimping tool MS 25037-1.

When the tool is used correctly, a deep crimp is placed in the B area of terminal lugs and splices, as shown in diagrams on the right of the figure. A shallow crimp is applied to the portion of the terminal or splice which extends over the insulation of the wire, as indicated by the A area in the diagrams. This clamping action is provided by a recessed portion in the other side of the divided jaw. A guard, which should be in the position shown when crimping terminals, aids in proper positioning of the terminal. However, the guard must be moved out of the way when the tool is used for crimping splices, and it may not always be replaced when it should be.

Without the guard, the tool may be used incorrectly; for example, the terminal might be inserted from the wrong side of the tool. The result is that the deep crimp is placed in the A area of the terminal or splice and, although the wire may be held securely in place, the connection is poor. Common sense indicates the deep crimp must clamp the metal of the terminal to the bare metal of the wire to provide a good electrical and mechanical connection.

The MS 25037-1 tool requires occasional checking. A No. 36 (0.106) drill rod should not be able to enter the smaller (red or blue) nest when the tool is fully closed. If it does enter, have the tool repaired.

Instruction in proper crimping procedure should be furnished to all who need to make solderless terminal connections. *Handbook of Installation Practices for Aircraft Electric and Electronic Wiring*, NAVAIR 01-1A-505, contains detailed procedures for using many solderless connector tools.

Type MS 3191-3

This tool is the latest standard crimping tool designed specifically for use with type MS 3191 contacts for electrical connectors. It features interchangeable heads to accommodate various size terminals. It may be used with the turret (fig. 2-9 (A)) for normal use, or without the turret (fig. 2-9 (B)) for eyeball crimping (when material alignment does not allow use of the turret).

Before you use the tool, the correct selection must be made on the positioner head and also on the indentor gap selector plate. To release the turret for indexing, press the trigger and the spring-loaded turret snaps out to its indexing position. Select the desired position from the color-coded nameplate and rotate the turret to align the selected positioner with the index. Depress the turret until flush, and the turret will automatically lock into place. To prevent further indexing, insert the lockwire through the hole provided in the trigger.

To crimp a terminal, select the proper size and type terminal and insert the prepared wire into the contact pocket until the wire seats on the bottom. The wire should be visible through the inspection hole, and the insulation should enter the contact insulation support. Insert the contact and wire into the terminal crimping tool, making sure that the contact is properly seated in the positioner. Actuate the crimping tool handles to crimp the contact and wire. At the completion of the stroke, the ratchet releases; open the handles and remove the crimped contact from the tool.

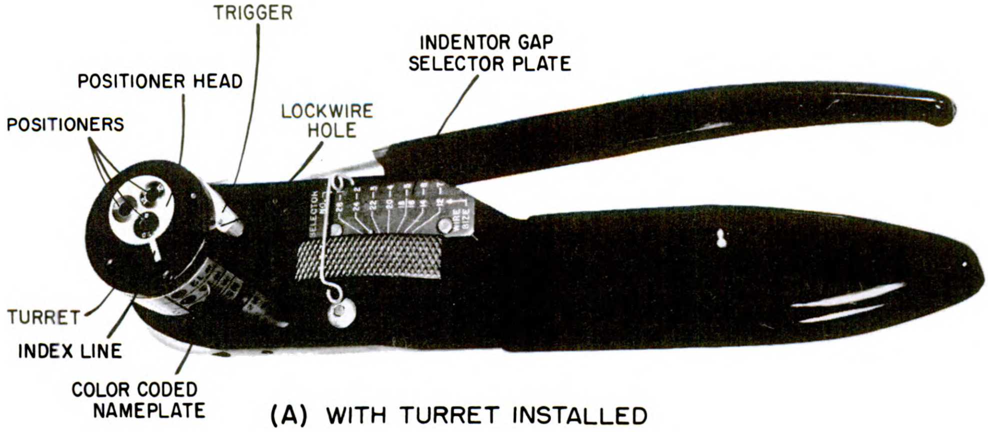
Inspect the crimped terminal and wire. The wire must be visible through the inspection hole. The insulation must be inside the insulation support. The crimping indents must be positioned between the inspection hole and the front of the insulation support. The contact must not be bent. The crimped contact is now ready to be installed into a connector.

For eyeball crimping, remove the head assembly from the tool. Select the proper wire size and move the thumb button until the pointer is aligned with the selected wire size on the indentor gap selector plate. Holding the contact in the crimping tool, slowly close the handles, and at the same time position the contact so the indentors are positioned midway on the contact barrel. Insert the wire, making sure it is bottomed in the contact, then close handles fully.

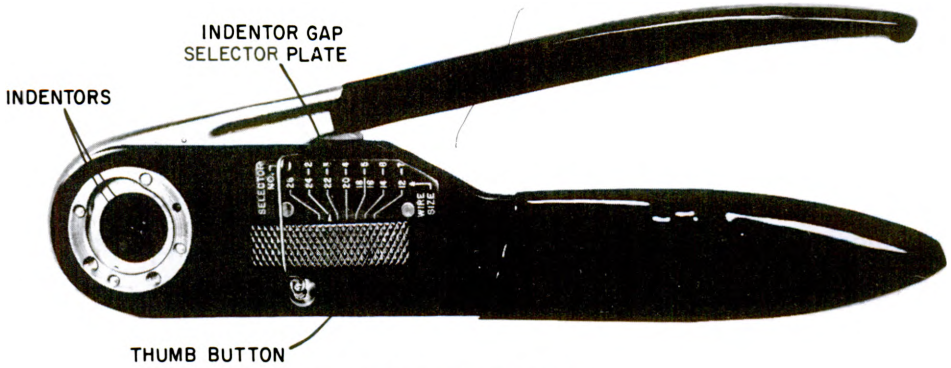
After releasing the handles, remove and inspect the crimped contact. The contact must not be fractured, and the conductor must be visible in the inspection hole.

SOLDERING GUNS, IRONS, AND TIPS

Soldering tools used in aviation maintenance activities come in many sizes and models. They may be of the gun type or of the common iron type. Irons come in a wide range of wattage



(A) WITH TURRET INSTALLED



(B) WITH TURRET REMOVED

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Figure 2-9.—Crimping tool MS 3191-3.

ratings, and may operate on 28 volts d.c. or 115 volts a.c.

The iron most commonly used in avionics maintenance is the pencil type. (See fig. 2-10.) You should use this tool and its special tips in those instances when the applied heat must be kept to a minimum. These operations include all cases involving transistors, printed circuit repair, miniaturized components, and so forth.

Because of its rapid heating and cooling, the oldering gun has gained great popularity in recent ears. You will find it especially well adapted to naintenance and troubleshooting work where nly a small part of your time is spent actually oldering. A continuously hot iron oxidizes apidly and is difficult to keep clean.

A transformer in the gun supplies about 1 volt at high current to a loop of copper that serves as the tip. It heats to soldering temperature in 3 to 5 seconds, but will heat to as high as 1,000 °F if left on longer than 30 seconds. Because it operates for short periods of time, very little oxidation is allowed to form; thus, it is one of the easiest soldering tools to keep well tinned. (Tinned refers to the tin alloy protective coating on soldering tips.) On the other hand, this tip is made of pure copper with no plating, so pitting can easily occur as a result of the dissolving action of the solder. Offsetting this disadvantage, however, is the low cost of replacement tips.

To obtain best results from a soldering gun or iron, the tip must be kept free of

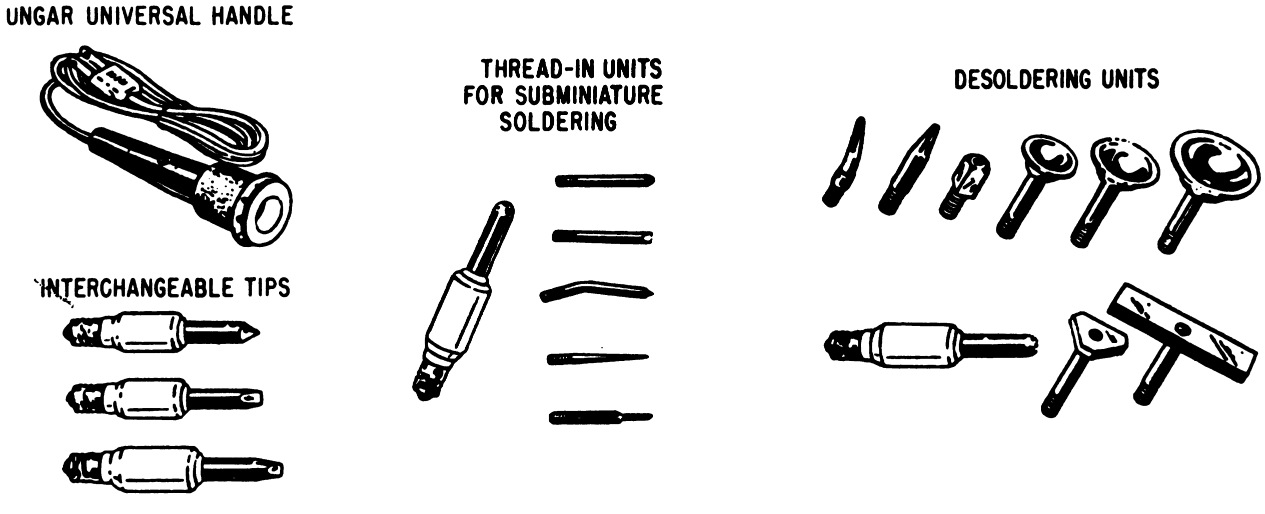

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Figure 2-10.—Pencil iron with special tips.

oxide and scale. Most technicians wipe the tip on cloth, then file and retin as necessary.

A faster way is the "damp sponge" method. A dampened cellulose sponge is secured in a container such as a soap dish or metal ashtray. (The sponge is more effective than the cloth in keeping the tip clean and presents no safety problems.) The damp sponge will prevent the splattering that sometimes occurs when the heated tips are wiped off in the usual way, and it will also absorb particles that may otherwise injure your face. The sponge eliminates oxide and scale, so filing and retinning are kept to a minimum.

Resistance Soldering Unit

A time-controlled resistance soldering set (fig. 2-11) is available through normal supply channels. The set consists of a transformer that supplies 3 or 6 volts at high current to stainless steel or carbon tips. The transformer is turned ON by a foot switch and OFF by an electronic timer. The timer can be adjusted for as long as 3 seconds soldering time. This set is especially useful for soldering cables to AN plugs and similar connectors, even the smallest types.

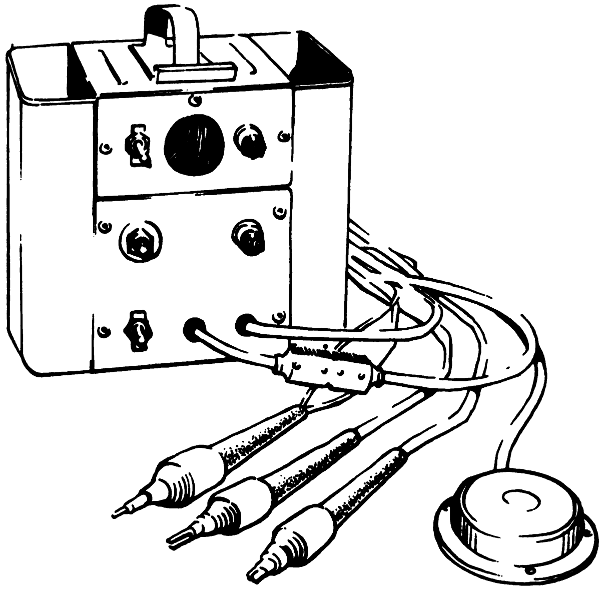

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Figure 2-11.—Resistance soldering unit.

In use, the double-tip probes of the soldering unit are adjusted to straddle the connector cup to be soldered. One pulse of current heats it for tinning and, after the wire is inserted, a second pulse of current completes the job. Since the soldering tips are hot only during the brief period of actual soldering, burning of the wire insulation and melting of connector inserts are greatly minimized.

MECHANICAL FINGERS

Small articles which have fallen into places where they cannot be reached by hand may be retrieved with the mechanical fingers. This tool is also used when starting nuts or bolts in difficult areas. The mechanical fingers (fig. 2-12) have a tube containing flat springs, which extend from the end of the tube to form clawlike fingers, much like the screw holder of a screwdriver. The springs are attached to a rod that extends from the outer end of the tube. A plate is attached to the end of the tube, and a similar plate, to be pressed by the thumb, is attached to the end of the rod. A coil spring placed around the rod between the two plates holds them apart and retracts the fingers into the tube. With the bottom plate grasped between the fingers and enough thumb pressure applied to the top plate to compress the spring, the tool fingers extend from the tube in a grasping position. When the thumb pressure is released, the tool fingers retract into the tube as far as the object they hold will allow. Thus, enough pressure is applied on the object to hold it securely. Some mechanical fingers have a flexible end on the tube to permit their use in close quarters or around obstructions.

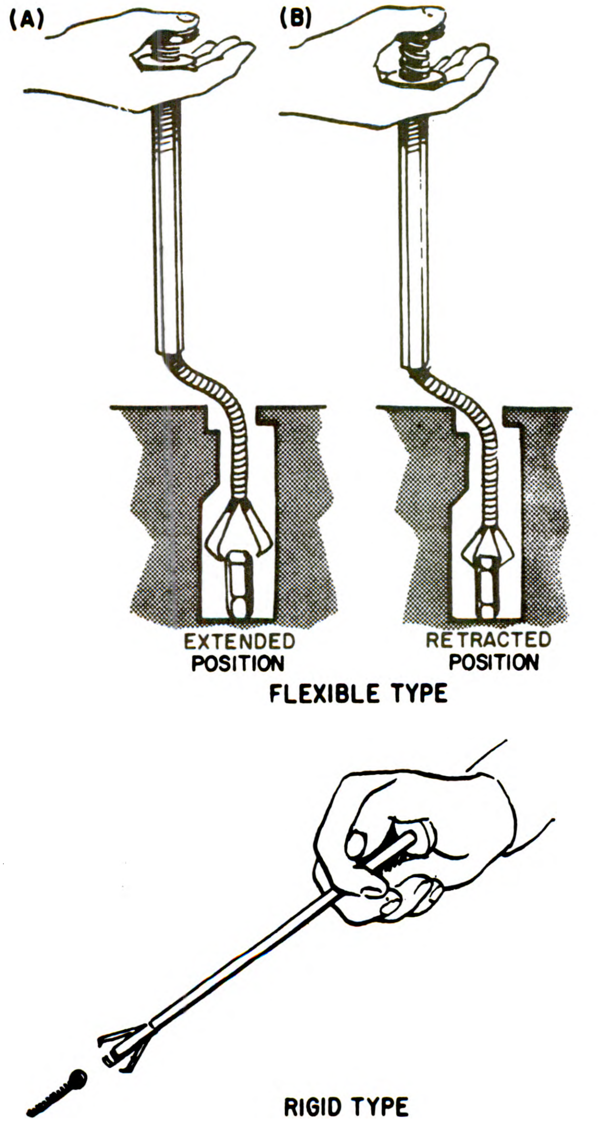

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Figure 2-12.—Mechanical fingers.

NOTE: You should not use mechanical fingers as a substitute for wrenches or pliers. The fingers are made of thin sheet metal and can be easily damaged by overloading.

STEEL SCALE

The steel scale (fig. 2-13) is a measuring device that will usually be found in a toolbox. It is

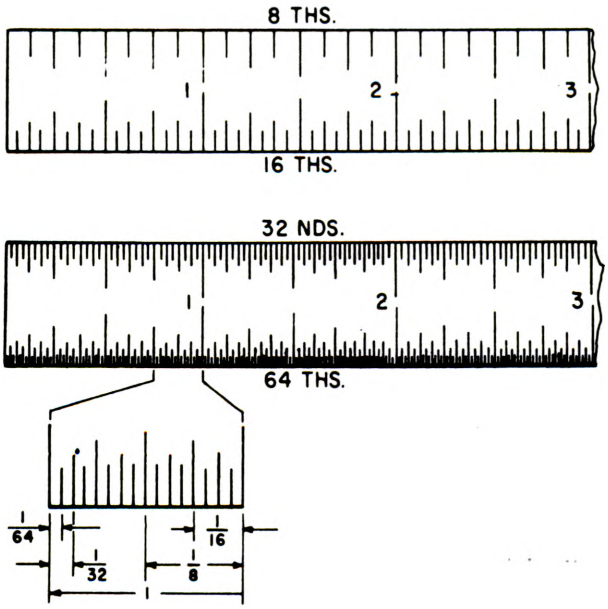

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Figure 2-13.—Steel scale.

graduated in divisions of 1/8 and 1/16 inch on one side and 1/32 and 1/64 inch on the other side. The steel scale most commonly used is 12 inches long.

Measurements should be taken with a steel scale by holding it on its edge on the surface of the object being measured. This will prevent you from making errors which might be caused by the thickness of the scale. Such thickness causes the graduations to be a slight distance away from the surface of the object. Measurements are read at the graduation which coincides with the distance to be measured.

FLASHLIGHT

Your toolbox should have a standard Navy vaporproof two-cell flashlight. The flashlight is used constantly during all phases of maintenance. Installed in both ends of the flashlight are rubber seals which keep out all vapors. You should inspect the flashlight periodically for the installation of these seals, the spare bulb, and red lens which are contained in the end cap. NOTE: Do not throw away the red lens; you may need it for night operations.

INSPECTION MIRROR

There are several types of inspection mirrors available for use in aircraft maintenance. The mirror is issued in a variety of sizes and may be round or rectangular. The mirror is connected to the end of a rod and may be fixed or adjustable (fig. 2-14).

The inspection mirror aids in making detailed inspection where the human eye cannot directly see the inspection area. By angling the mirror, and with the aid of a flashlight, it is possible to inspect most required areas.

CANNON PLUG PLIERS

Figure 2-15 displays a set of special pliers used to remove electrical connectors when they are on so tight that they cannot be removed by hand. These pliers, when properly used, will prevent damaging or destroying electrical connectors.

TOOL CONTROL PROGRAM, SHOP TOOLS, AND CENTRAL TOOLROOMS

Aircraft accidents and incidents attributable to tools being left in aircraft after maintenance work has been performed are major problems. To reduce the potential for tool FOD (foreign object damage) related mishaps, a tool control program (TCP) has been developed. This program provides you with the means of rapidly accounting for

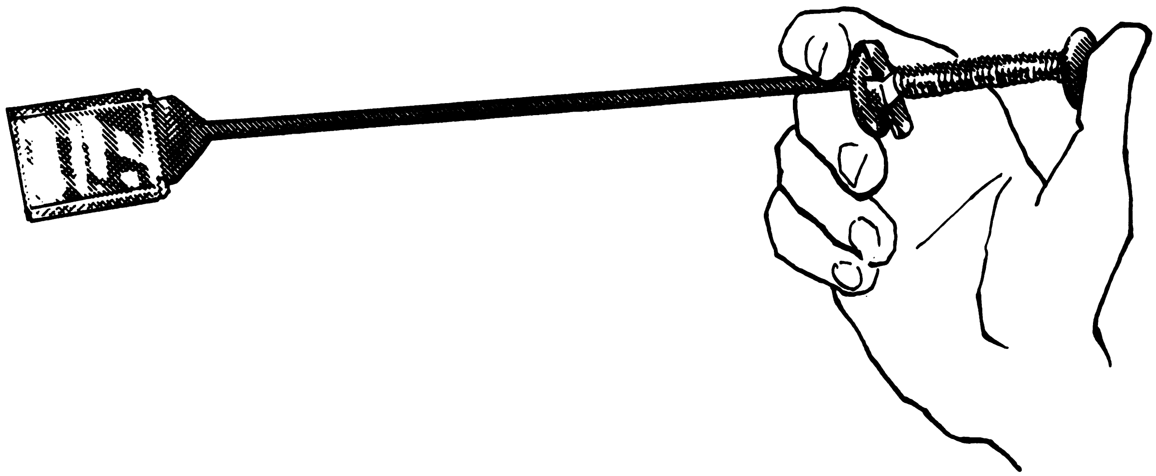

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Figure 2-14.—Typical inspection mirror.

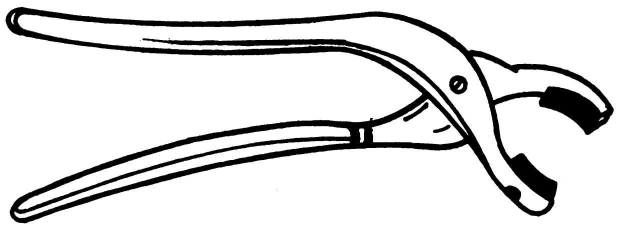

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Figure 2-15.—Cannon plug pliers.

all tools after you have completed a maintenance task on an aircraft or its related equipment.

The TCP is based on the instant inventory concept. Basically the program provides internally configured, silhouetted tool containers, when applicable, so that all tools have individual locations to highlight a missing tool.

All tools are etched to denote the work center, organization, and tool container it belongs to. All containers are marked to identify work center, work package, maintenance level, and organization on the exterior. If possible, the container contains a silhouette of each tool in its proper place. On containers where silhouetting is not feasible, a note with the inventory and drawing of the container outline should be included. Either system enables the work center supervisor or inspector to quickly ensure that all tools have been retrieved after a maintenance action.

The most significant benefit of this program is the lives and equipment that are saved by eliminating tool-FOD-caused accidents. Additional desirable benefits are reduced initial outfitting and tool replacement costs, reduced tool pilferage, reduced man-hours required to complete each maintenance task, and ensurance that proper tools are available for specific maintenance tasks.

Shop tools are the larger, low-usage, and special tools for use on specific equipment. A shop tool bin is normally utilized to make available to the technician those special tools and medium-usage tools needed to perform the various phases of shop maintenance. However, shop tools also nclude any handtools required to perform more extensive maintenance than can be accomplished rom a toolbox. To determine the types and number of shop tools allowed, refer to the allowance list from the NAVAIR 00-35QG-016.

THE CENTRAL TOOLROOM

Most shore-based squadrons with aircraft that do not deploy aboard aircraft carriers, and most Aviation Intermediate Maintenance Departments (AIMDs), have a central toolroom. When this is the case, the toolroom is usually under the direction of the material control work center. The duties of this element include the following:

1. Maintaining tools on hand for temporary checkout and replacement for broken tools
2. Initiating requests for required tools
3. Maintaining custody receipts and checkout slips for "one-of-a-kind" tools, accountable Individual Material Readiness List (IMRL) items such as power tools, special tools, and in some cases general electronics test equipment
4. Maintaining tool box inventory records and records specifying to whom tools and tool boxes are issued
5. Inventorying tool boxes
6. Marking all handtools

MAINTAINING TOOL ACCOUNTABILITY IN ACTIVITIES WITHOUT CENTRAL TOOLROOMS

In squadrons with carrier type aircraft assigned, the establishment of a toolroom is a rare exception. Therefore, other procedures must be followed to maintain accountability. In these situations, the toolroom responsibilities are usually divided among the various work center supervisors. In many such squadrons, it is the responsibility of one work center supervisor to inventory the tool boxes of a different work center. For example, the powerplants work center supervisor may be required to inventory the tool boxes of the airframes work center. Also, in many activities, the quality assurance work center is responsible for the inventory of tool boxes and for monitoring the tool control program in all activities.

Even in these types of activities, the material control work center still usually keeps a duplicate copy of all tool box inventory sheets; checks out and maintains custody card/receipts for "one-of-a-kind" tools and accountable power handtools and special tools; and orders all tools required for replacement.

THE TOOL BOX INVENTORY

No matter which work center performs the tool box inventory the procedures are fairly standard. The following subparagraphs contain some of these standard procedures.

1. Marking tools. All tools should be marked to clearly indicate to which tool box they belong. One of the common methods is to etch the particular tool with the work center number and the tool box number. For example, a wrench that belonged in tool box number 4 of work center 260 would be marked 260-4. This method allows anyone who finds a misplaced tool to determine which tool box the tool belongs in.

2. The inventory record. The material control work center usually prepares a master inventory sheet that lists the tools maintained in tool boxes in the whole squadron or in a particular work center. The work center supervisor then marks the type and quantity of tools required by work center personnel. The material control work center then fills the tool box to those specifications and has the person who is to take custody of the box to sign the inventory sheet which has the actual quantities in that particular tool box annotated on it. This "master" inventory sheet is then maintained on file in the maintenance office, quality assurance, material control, or the toolroom, depending on local instructions. The person who has custody of the tool box is given a duplicate copy for the inventory records. The "master" copy is then used for periodic inventories of the tool box.

3. Shortages. Any shortages found during inventory should be reported to the maintenance officer via the applicable work center supervisor and quality assurance. A local form, such as the one illustrated in figure 2-16, could be used for this purpose.

AIRCRAFT HARDWARE AND CONSUMABLE MATERIALS

As a maintainer of aircraft equipment, you will be interested in certain items of hardware and consumable material. Hardware and material are used for both the installation of equipment and the repair of installed equipment. In all instances, the proper parts and material should be used. If substitution becomes necessary, care must be taken to ensure that the substitute item is satisfactory in all respects.

Items of hardware and material necessary for aircraft maintenance are specified in the applicable maintenance instruction manuals. In some instances, you may have to go into the Navy supply system. The latter part of this chapter tells you "where to look," and gives you some of the details of the system. Before that, however, let's look at some of the gadgetry used for mounting parts.

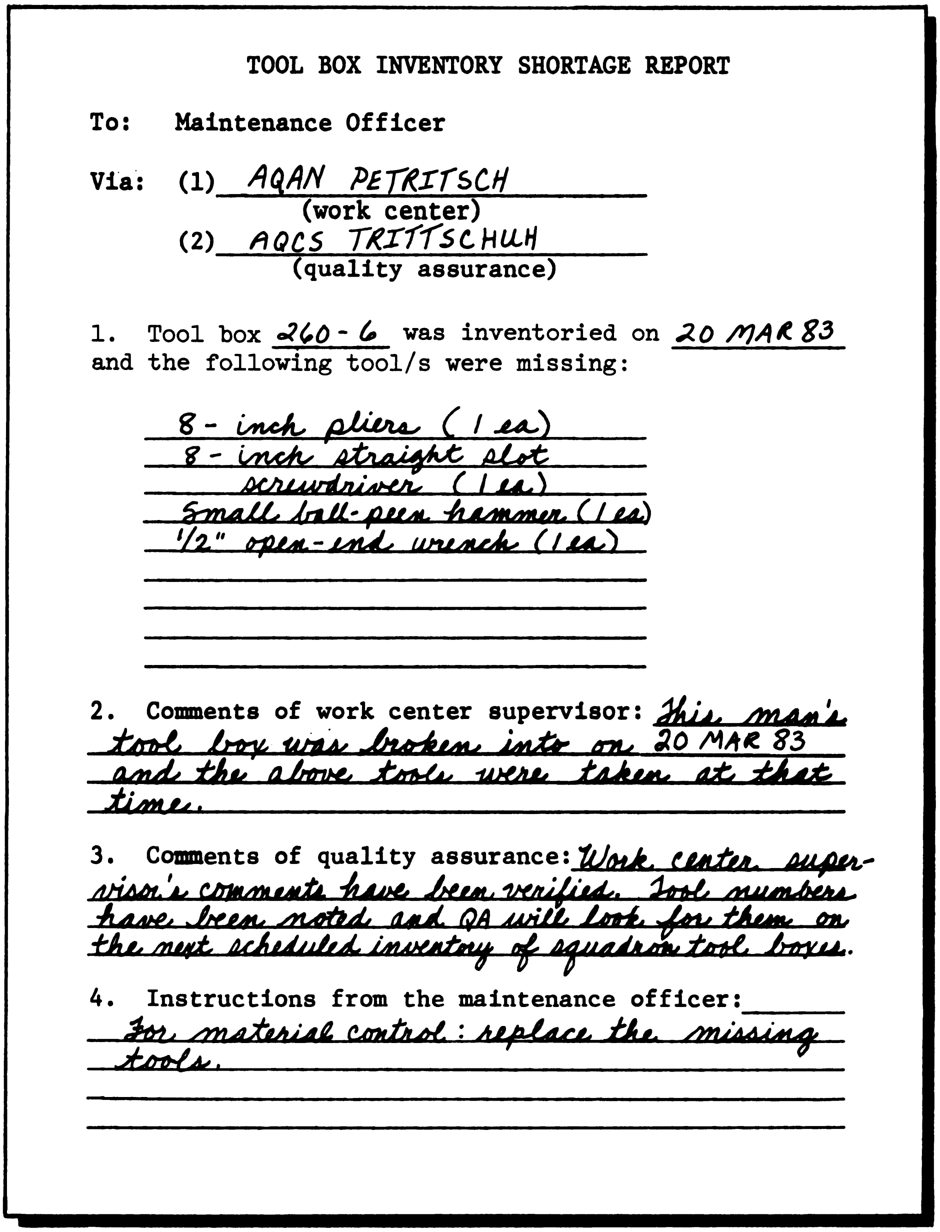
MOUNTING PARTS

It is not always desirable to use the same mounting parts that were removed from the installation. Prior to reinstalling the same items, an inspection must be made to ensure the parts are of the type specified, and are not defective or damaged. It must also be determined that instructions do not forbid their reuse. Then, and only then, should the removed parts be reinstalled.

Information concerning the use of mounting parts, such as screws, nuts, bolts, and washers, is of a general nature. You should follow established doctrine for their use. We discuss the use of such items, to a limited degree, later in this chapter in a section dealing with the "substitution of parts." *Aircraft Structural Hardware for Aircraft Repair*, NAVAIR 01-1A-8, is a valuable source for detailed information.

TURNLOCK FASTENERS

Turnlock fasteners are used to secur inspection plates, doors, and other removabl



TOOL BOX INVENTORY SHORTAGE REPORT

To: Maintenance Officer

Via: (1) AQAN PETRITSCH
(work center)
(2) AQCS TRITTSCHUH
(quality assurance)

1. Tool box 260-6 was inventoried on 20 MAR 83 and the following tool/s were missing:

8-inch pliers (1 ea)
8-inch straight slot screwdriver (1 ea)
Small ball-peen hammer (1 ea)
1/2" open-end wrench (1 ea)

2. Comments of work center supervisor: This man's tool box was broken into on 20 MAR 83 and the above tools were taken at that time.

3. Comments of quality assurance: Work center supervisor's comments have been verified. Tool numbers have been noted and QA will look for them on the next scheduled inventory of squadron tool boxes.

4. Instructions from the maintenance officer: For material control: replace the missing tools.

211.7

Figure 2-16.—Sample local form for reporting shortages in tool box inventory.

panels on aircraft. Turnlock fasteners are also referred to by such terms as quick-opening, uick-action, and stress panel fasteners. The nost desirable feature of these fasteners is hat they permit quick and easy removal of ccess panels for inspection and servicing urposes.

Turnlock fasteners are manufactured and supplied by a number of manufacturers under various trade names. Some of the most commonly used are the Camloc stress panel fastener, and Airloc, both of which are discussed in this section. Other turnlock fasteners are covered in the rate training manual *Airman*, NAVEDTRA 10307 (Series).

Camloc Stress Panel Fasteners

The Camloc stress panel fastener (fig. 2-17) is a high-strength, quick-release, rotary type fastener and may be used on flat or curved, inside or outside panels. The fastener may have either a flush or nonflush stud. The studs are held in the panel with flat or cone-shaped washers, the latter being used with flush fasteners in dimpled holes.

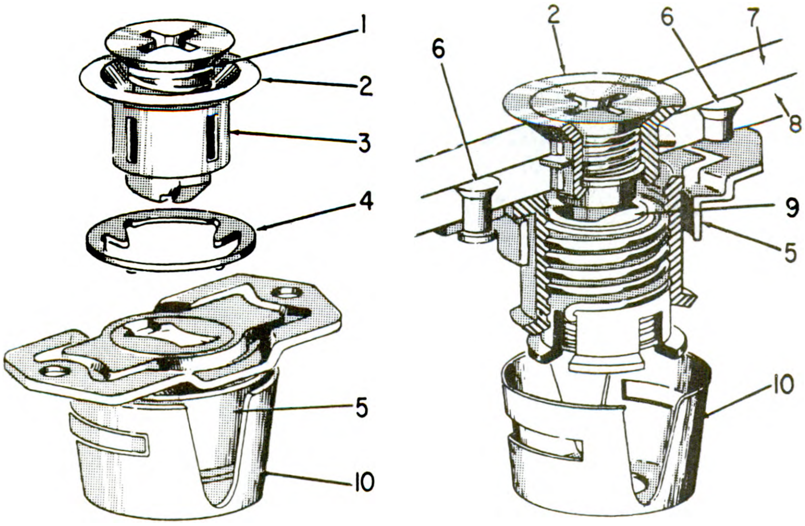
This fastener may be distinguished from screws by the deep No. 2 Phillips recess in the stud head and by the bushing in which the stud is installed. A threaded insert in the receptacle provides an adjustable locking device. As the stud is inserted and turned counterclockwise 1/2 turn or more, it screws out the insert sufficiently to permit the stud key to engage the insert cam when turned clockwise. Rotating the stud clockwise 1/4 turn engages the insert, and continued rotation screws the insert in, tightening the fastener. Turning the stud 1/4 turn counterclockwise will then release the stud but will not screw the insert out far enough to permit reengagement in installation. It is necessary to turn the stud at least 1/2 turn counterclockwise to reset the insert.

To unlock the stress panel fastener and reset it in the same operation, use a No. 2 Phillips screwdriver to turn the stud counterclockwise 1/2 turn or more. Do not turn the stud past the stop.

CAUTION: Do not use a power screwdriver on this fastener.

To lock, use a Phillips No. 2 screwdriver, push the stud in, and turn clockwise until increased torque is felt; then continue turning until the fastener is tight.

NOTE: When installing a large panel, it may be necessary to engage all the fasteners before tightening. This is done by pushing each stud in



1. Tension spring.
2. Stud assembly.
3. Bushing.
4. Retaining ring.
5. Receptacle assembly.
6. Receptacle attaching rivets.
7. Outer skin.
8. Inner skin.
9. Insert
10. Cover.

217.6

Figure 2-17.—Camloc stress panel fastener.

and turning it clockwise 1/4 turn. The stud should engage the receptacle but remain loose. If the stud does not engage, it will pop out, indicating that the insert must be reset by turning the stud counterclockwise 1/2 turn or more.

Airloc Fastener

The Airloc fastener consists of a stud, stud cross pin, and a receptacle (fig. 2-18.) The stud is attached to the access cover, and is held in place by the cross pin. The receptacle is riveted to the access cover frame. A quarter turn of the stud (clockwise) locks the fastener in place; turning the stud counterclockwise, unlocks the fastener.

THREADED FASTENERS

Threaded fasteners are covered in the rate training manual, *Airman*, NAVEDTRA 10307 (Series). However, a brief discussion of "Torq-Set" screws, a new development in threaded fasteners, is included in this text.

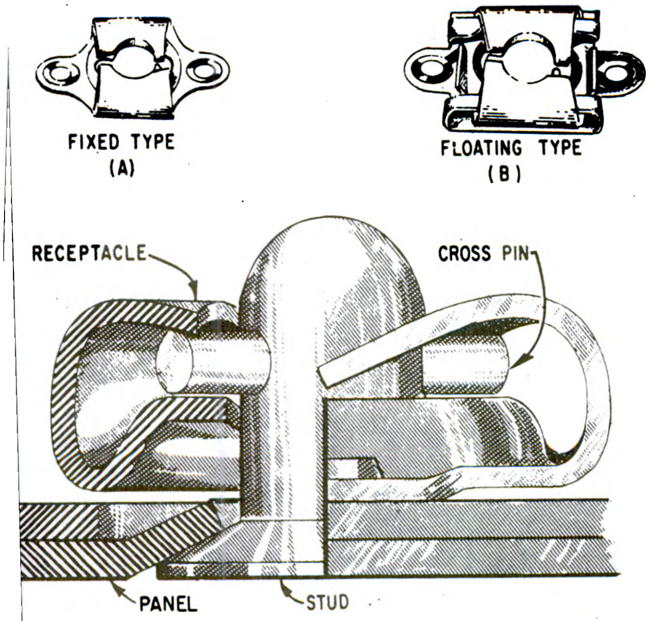


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Figure 2-18.—Airloc fastener.

"Torq-Set" Screws

"Torq-Set" machine screws (offset cross-slot drive) have begun to appear in new equipment. The main advantage of the newer type is that more torque can be applied to its head while tightening or loosening, than any other screw of comparable size and material, without damaging the head of the screw.

Torq-Set machine screws are similar in appearance to the more familiar Phillips machine screws.

You should be aware of the difference between a Phillips machine screw and a Torq-Set screwhead (fig. 2-19). A Phillips head screwdriver could easily damage a Torq-Set screwhead, making it difficult, if not impossible to remove the screw, even if the proper tool is later used.

Torque Information

You may use the torque table (table 2-1) as a guide in tightening nuts, bolts, and screws whenever specific torque values are not called out in maintenance procedures. Using the proper torque allows the structure to develop its designed strength and greatly reduces the possibility of failure due to fatigue.

Threads must be free from grease or oil. Lubrication changes the torque value and will result in overtorquing.

When castellated nuts are used, they should be tightened to the lower torque limit; then

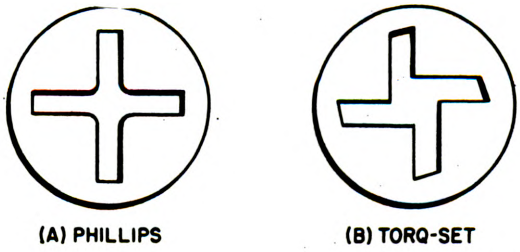

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Figure 2-19.—Comparison of Phillips and Torq-Set screwheads.

Table 2-1.—Torque values in inch-pounds

Wrench size (in.)	Standard nuts, bolts, and screws		
	Bolt, stud, or screw size	Tension type nuts AN310 and AN365	Shear type nuts AN320 and AN364
1/4	4-48	4-5.5	2.5-3.5
5/16	6-40	7.5-11	4.5-6.5
11/32	8-36	12-15	7-9
3/8	10-32	20-25	12-15
7/16	1/4-28	50-70	30-40
1/2	5/16-24	100-140	60-85
9/16	3/8-24	160-190	95-110
5/8	7/16-20	450-500	270-300
3/4	1/2-20	480-690	290-410
7/8	9/16-18	800-1,000	480-600
15/16	5/8-18	1,100-1,300	660-780
1 1/16	3/4-16	2,300-2,500	1,300-1,500
1 1/4	7/8-14	2,500-3,000	1,500-1,800
1 7/16	1-14	3,700-5,500	2,200-3,300

NOTE: To convert to foot-pounds, divide inch-pounds by 12.

continue tightening until the cotter pin hole is aligned with slots in nut. Do not back off nut to align hole.

When it is necessary to tighten from the bolthead, use the high side of the torque range. If necessary, the maximum allowable tightening torque may be used.

When corrosion-resistant steel bolts are used, they should be lubricated with an antiseize compound. Corrosion-resistant steel bolts and nuts must be used together. Use shear nut torque values when tightening these bolts.

CONNECTORS

In the discussion which follows, we use the word "connector" in a general sense. It applies equally well to connectors designated by "AN" numbers and those designated by "MS" numbers. Formally, all supply items cataloged jointly by the Army and Navy used AN numbers. Many items, especially those of older design, continue to carry the AN designator, even though the supply system is shifting over to MS (Military Specification) numbers.

Connector Construction

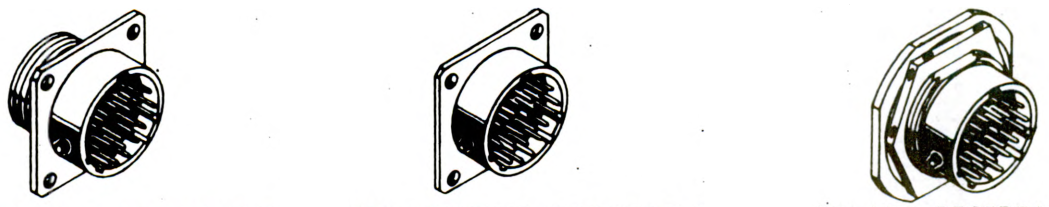
Electrical connectors are designed to provide a detachable means of coupling between major components of electrical and electronic equipment. These connectors are constructed to withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage drop despite extreme vibration, rapid shifts in temperature, and great changes in altitude.

These connectors vary widely in design and application. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut, and each consists of an aluminum shell containing an insulating insert which holds the current-carrying contacts. The plug is usually attached to a cable end and is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected and is usually mounted on a part of the equipment.

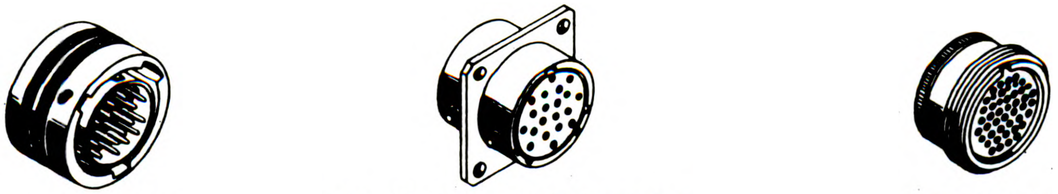
There are wide variations in shell type, design, size, layout of contacts, and style of insert. Six types of connector shells are shown in figure 2-20.

The shells of MS connectors are made in eight types, each for a particular kind of application. A letter designation is used in the MS number to indicate the shell design, as in MS 3106E, where E is the shell type indicator. The shell indicators are as follows:

A — Solid shell
B — Split shell
C — Pressurized type
D — Sealed construction
E — Environment resistant
F — Vibration resistant
H — Flame barrier shell
K — Fireproof construction



WALL MOUNTING RECEPTACLE BOX MOUNTING RECEPTACLE JAM NUT RECEPTACLE



STRAIGHT PLUG THRU-BULKHEAD RECEPTACLE SHORT PLUG

222.6

Figure 2-20.—Connector shells.

Solid shell connectors are used where no special requirements, such as fireproofing or moistureproofing, must be met. The rear shells are made from a single piece of aluminum.

Split shell connectors allow maximum accessibility to soldered connections. The rear shell is made in two halves, either of which may be removed. Figure 2-21 shows an exploded view of one type of a split shell connector.

Pressurized connectors provide a pressure-tight feed-through for wires that pass through walls or bulkheads of pressurized compartments in high altitude aircraft. The contacts are usually molded into the insulator, and the shell is spun over the assembly to seal the bond.

Sealed connectors are employed in equipment that is sealed and operated under gas pressure. These connectors include a glass-to-metal seal and have either special rubber inserts or a cementing compound applied to the insert.

Vibration-resistant connectors are designed for use in equipment that is subjected to intense vibrations in installations on or near reciprocating engines.

Fireproof connectors are made under specifications which require the connector to maintain effective electrical service for a limited time even when exposed to fire. The inserts are made of a ceramic material, and special crimp type contacts are used.

Moisture-resistant connectors consist of a combination of the features of the solid shell, the pressurized, and the vibration-resistant types. The component parts of this kind of connector are shown in figure 2-22.

Each connector is given an identification symbol called the MS part number. This symbol indicates the shell type, the shell design, the size, the insert type, the insert style, and the insert position. An example is the designator MS 3100-A-16-11 PX.

The letters MS form the prefix. The number 3100 indicates the shell type and identifies the connector as one of the types shown in figure 2-20.

The letter A indicates a solid shell connector. The number 16 is the shell size.

The number 11 is a designation of the insert pin arrangement used in the connector. A

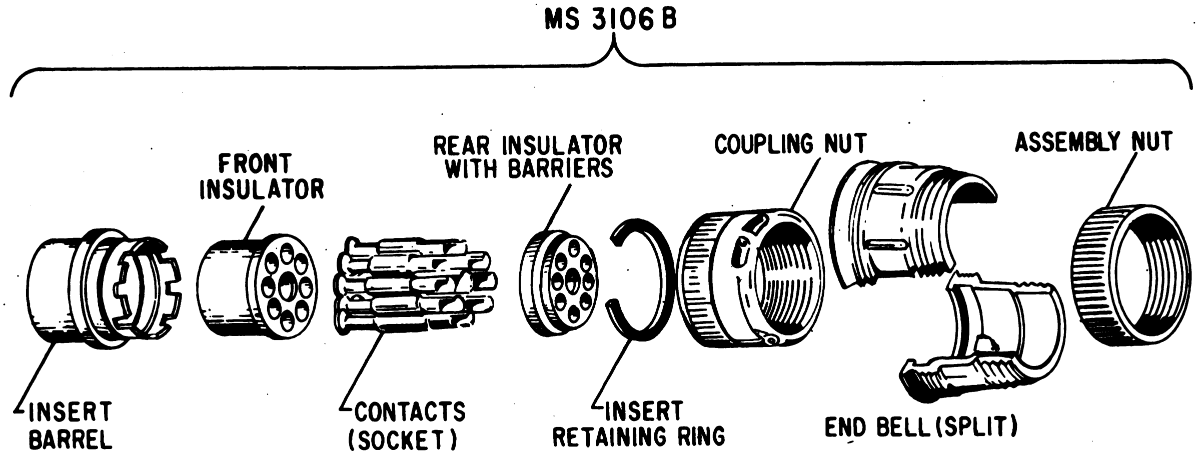


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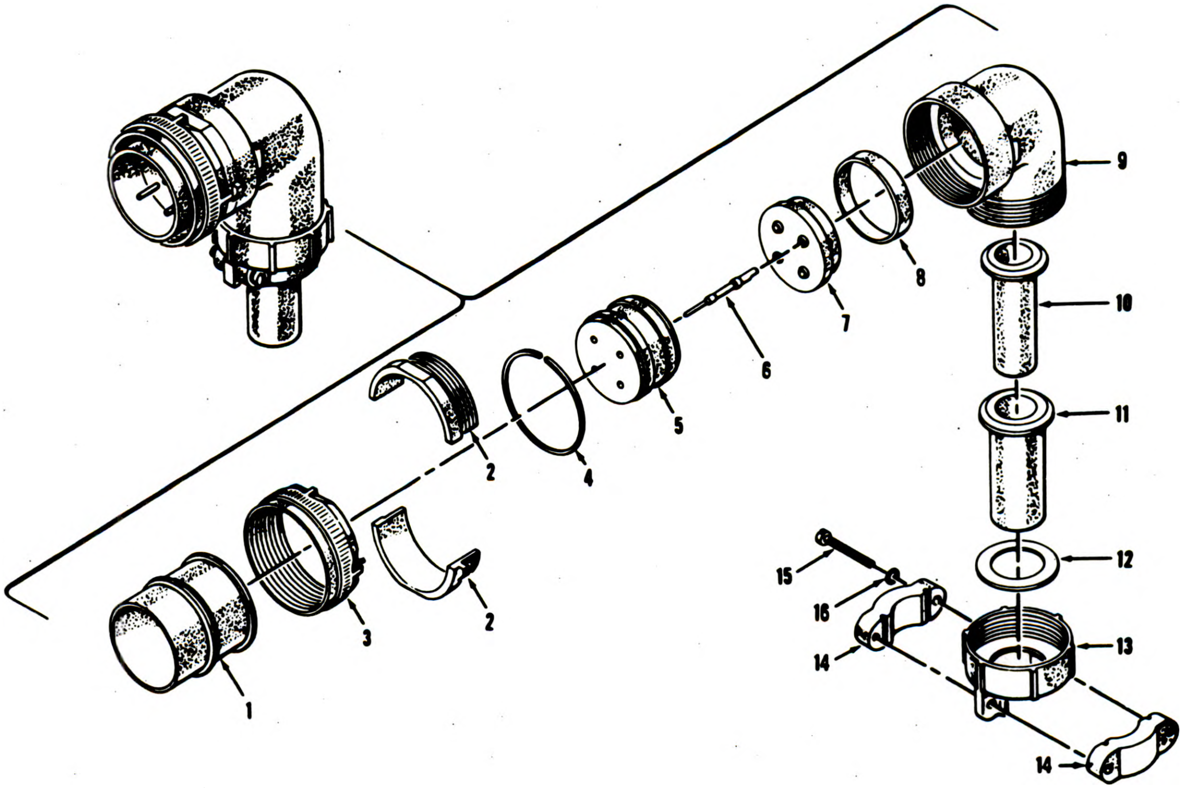
Figure 2-21.—Exploded view of a split-shell connector.



1. Insert barrel.
2. Split nut (half).
3. Coupling nut.
4. Split-nut retaining ring.
5. Insulator.
6. Contact (pin).
7. Grommet.
8. Ferrule.
9. Angle—90° end bell.
10. Telescoping gland busings.
11. Telescoping gland busings.
12. Bushing washers.
13. Gland-clamp fittings.
14. Clamp saddles.
15. Clamp-saddle screws.
16. Lockwashers.

207.60

Figure 2-22.—Exploded view of a 90° angle connector.

chart showing various pin arrangements may be found in the Operation and Service Instructions Manual, *AN Electrical Connectors* (AN-03-5-90).

The letter P means the insert is a pin, or male, insert. (The letter S is used to indicate a socket, or female, insert.)

The concluding letter, X, is a designation of the insert position. Connectors specially designed for a particular application sometimes have nonstandard contact, or insert, positions. Four positions of the inserts are employed, and these are called W, X, Y, and Z. Each letter refers to an angle by which the insert is rotated from the standard position. When the standard position is employed, no letter is shown at the end of the MS designation.

Three common types of subminiature connectors are shown in figure 2-23. Since these connectors are the wire-connected type, they have no flanges for mounting. However, the receptacle shown in part (C) can be mounted with nuts and lockwashers. They are used on miniature instruments, switches, transformers, amplifiers, and relays.

The subminiature connectors described and shown in figure 2-23 have not proven sufficiently satisfactory and are not being used in new aircraft designs. Their use is limited to those aircraft in which they were initially installed.

The miniature connectors (MS 311X and 313X series) are intended to supersede these subminiature connectors. The miniature connectors differ from the types just described in their method of coupling and contact sizes. Two types of quick-disconnect couplings are provided—axial and bayonet.

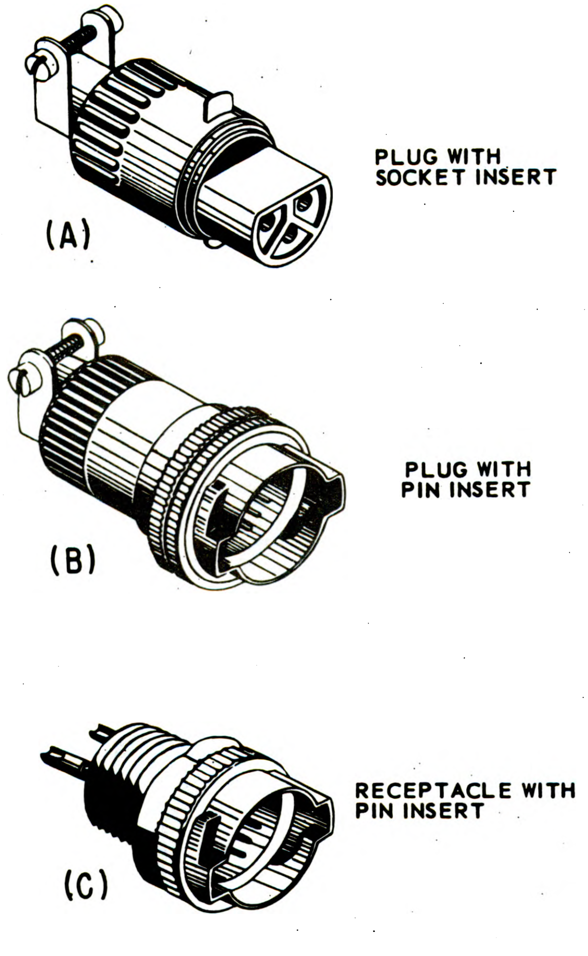


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Figure 2-23.—Subminiature connectors.

Through a reduction in size of contacts, from 0.062- to 0.040-inch diameter, a greater number of contacts per unit area can be achieved. The miniature connectors with smaller contacts rated at 7.5 amperes have found increased use through the advent of ac power in aircraft, where the majority of the circuits are low power and low current. All these connectors are environment resisting Class E. Hermetic receptacles and connectors suitable for potting are also provided in this series.

Coaxial connectors are divided into series and shown in figure 2-24. Each series consists of plugs, panel jacks, receptacles, and straight and right angle adapters.

Series UHF connectors are low-cost, general purpose connectors of nonconstant impedance. The small and large coaxial types are for use with small and medium size coaxial cables in applications where line imbalance or increased standing wave ratio is not important. Where impedance matching is necessary, C, N, or BNC series connectors are used. Both small and large series UHF connectors can be weatherproofed for outdoor use, but most are nonweatherproof.

The twin connectors are similar to the series UHF connectors except for the fact that they have twin center conductors and are to be used with small and medium sized twin-conductor cables. Twin connectors are available in small weatherproof and nonweatherproof types and large nonweatherproof types.

Series N connectors are the most popular constant impedance connectors for medium size coaxial cables. They can be used up through microwave frequencies with minimum line imbalance or increase in standing-wave ratio. Although series N 50-ohm and 70-ohm connectors do not mate, 70-ohm cables may be used with 50-ohm series N connectors where impedance matching is not critical. Series N connectors are completely weatherproof.

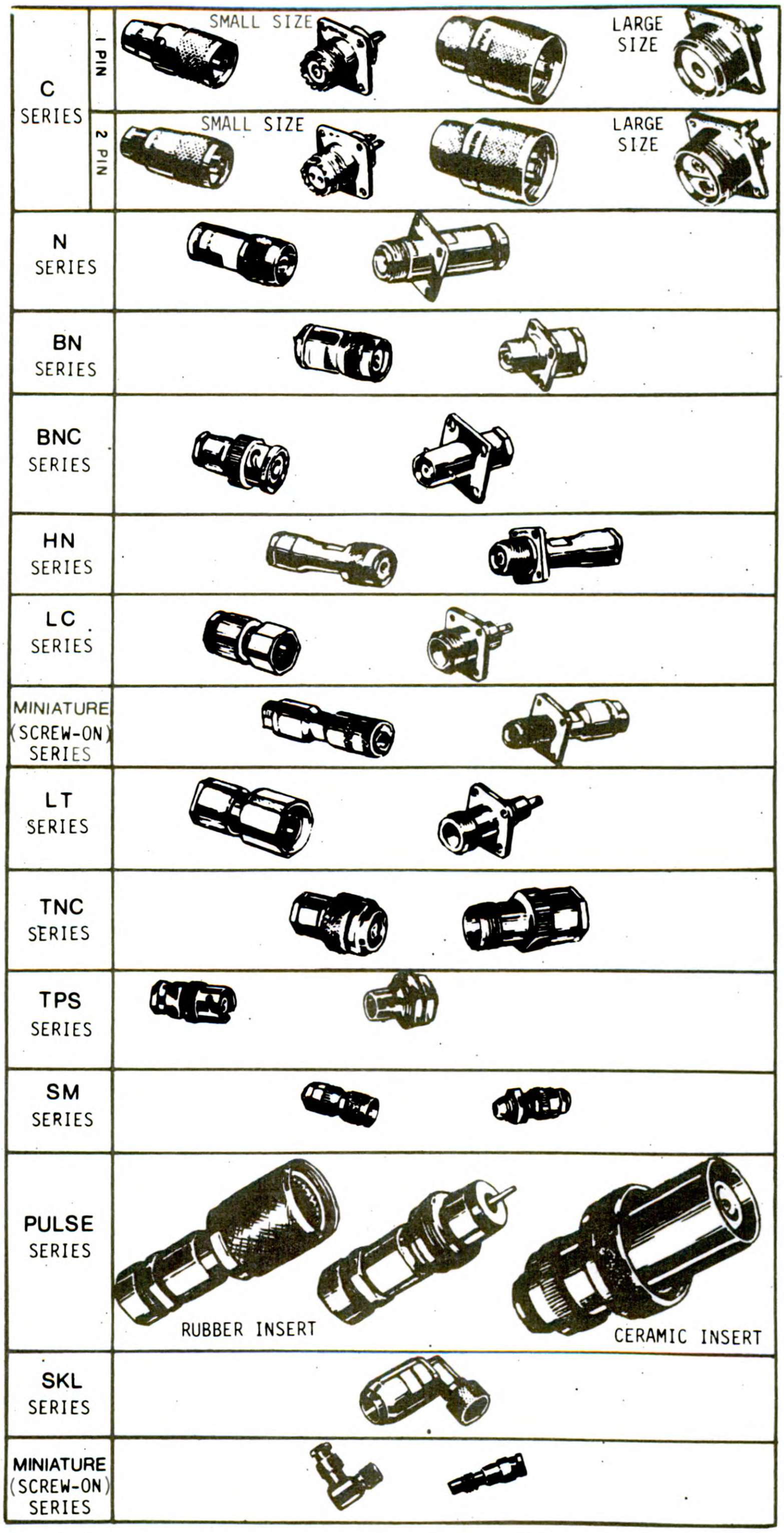

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Figure 2-24.—Several typical coaxial connectors.

Series C connectors are similar to 50-ohm series N connectors in that they are used with the same cables, are weatherproof, and can be used up through microwave frequencies. However, they are mechanically and electrically superior to series N connectors. Series C connectors feature bayonet-lock type coupling for quick connect and disconnect, an improved cable clamping mechanism for better cable grip with minimum cable indentation, and are intended for use up to 1,000 volts.

Series BNC connectors (fig. 2-25) are commonly used on small coaxial cables. All incorporate quick connect and disconnect bayonet-lock coupling and are weatherproof. Besides regular and modified low-voltage types of nonconstant impedance, improved series BNC connectors are available which have a constant 50-ohm impedance and yield excellent electrical performance up to 10,000 megahertz.

Series HN connectors are weatherproof, high-voltage connectors of constant impedance for use with 50-ohm rf cables.

Series LC connectors are large, 50-ohm, weatherproof connectors designed for applications involving the transmission of large amounts of rf power.

Series BN connectors are small, lightweight connectors (of nonconstant impedance) designed for use with the same coaxial cables which use BNC connectors. BN connectors are not recommended for applications at frequencies in excess of 200 megahertz unless electrical requirements of the circuit are not critical. They may be used at peak voltages up to 250 volts.

Series LT connectors are very similar in appearance to series LC; however, series LT differ not only in cable accommodation but are lighter than series LC connectors. Series LT connectors are large, 50-ohm, 5,000-volt connectors for use with Teflon RG-117/U cable.

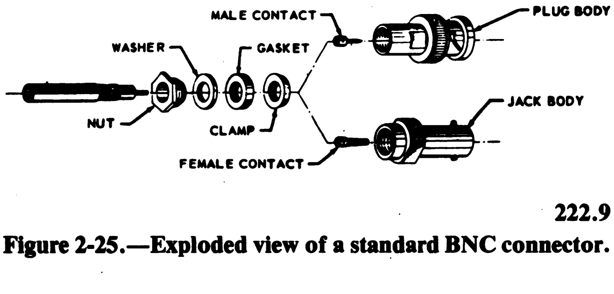

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Figure 2-25.—Exploded view of a standard BNC connector.

Series TNC connectors are basically identical with series BNC connectors. The major difference is that TNC connectors have a threaded type coupling instead of the bayonet-lock coupling. Consequently, TNC connectors are usually preferred in applications which are subject to extreme vibration.

Series TPS connectors are weatherproof and designed to produce minimum electrical discontinuities in small size 50-ohm coaxial cable up to a frequency of 10,000 megahertz. The connectors are rated at 1,500 volts rms at sea level; their use is governed by the temperature limitations of their associated cables.

Series SM connectors are nonweatherproof fittings for coaxial cables of 1/4-inch overall diameter and smaller. They may be used where electrical matching is not required. The SM connectors are smaller and contain fewer parts than the BNC series. The SM series employs a female center-conductor contact on plugs and a male center-conductor contact on jacks and receptacles. However, for consistency in cataloging and usage, a plug is still regarded as having a male mating end and a receptacle or jack as female. The SM series is not intended to replace the BNC series except for internal equipment connections where weatherproofness is required.

The pulse connectors are designed for high-voltage pulse or direct-current applications. They are nearly all weatherproof and available in three types—rubber-insert, ceramic-insert, and triaxial. The rubber-insert type PULSE connectors have a peak voltage rating of 5,000 volts at an altitude of 50,000 feet. They are designed principally for use with cables having an insulated Neoprene layer under the braid, such as RG-77/U and -78/U.

They may be used with cables employing a conducting rubber under the braid (such as RG-25/U, -26/U, and -64/U) provided special care is taken in assembling the connectors to these. The ceramic-insert pulse connectors are available in small (type A) and large (type B) sizes. Type A connectors are designed for use with the 8,000-volt RG-25/U, -26/U and type B with the 15,000-volt RG-27/U, -28/U cables. (Special care is required when assembling connectors to these.) Pulse connectors tend to leak noise which may interfere with communications equipment.

Triaxial connectors are used in transmission line applications where maximum rf shielding and minimum noise radiation are required. They are commercially available in sizes of the same diameter as the BNC series and C series (and possibly others). Some of these connectors have been used in military equipment and some within-series adapters are commercially available.

The SKL connectors were originally designed to provide a connection to a klystron tube. Newer klystrons are being equipped with BNC connectors. Various modifications were subsequently designed to provide general purpose cable-to-cable connections and adapters.

Miniature connectors have a gold finish, employ screw type coupling, and Teflon dielectric. They have a nominal impedance of 50 ohms, a sea-level breakdown voltage of 1,500 volts rms, a practical frequency limit of 10,000 megahertz, and are designed for operation up to 200 °C.

WIRE

Although modern technical literature has been emphasizing the use of printed circuits and microelectronic components in contemporary electronic equipment, wire is still important as a signal or current carrying device. Therefore, wire does deserve appropriate attention.

Since most naval equipment is of conventional construction, and complete conversion to the new forms of conducting components is not yet imminent, traditional wire conductors are in use, and probably will continue to be in use for some time to come. This means that when wire is to be requisitioned, either for installation or repair, care must be exercised in its selection. The three major factors involved in this selection, in descending order of importance, are size, insulation, and the characteristics required to satisfy specific environments in which the wire must function.

COAXIAL CABLES

Flexible coaxial cables (sometimes called RD cables) are a special type of cable used for carrying video and rf signals, cathode-ray-tube sweep currents and voltages, trigger range marks, blanking pulses, and other signals for radar receivers, transmitters, and indicators. These cables are constructed with special considerations for shielding, impedance, capacitance, and attenuation. All of these factors are of importance in many circuits. Coaxial cables have neither induction nor radiation losses. These lines have low attenuation even at very high frequencies and are used as high as 3000 MHz.

The name coaxial is derived from the construction, in that the inner and outer conductors have a common axis or coaxis. These cables consist of an inner conductor, a dielectric insulator, an outer conductor, and an outer covering. The inner conductor is usually made of copper, plain, tinned, or silver coated. The dielectric insulation is usually polyethylene, although other materials are used. The outer conductor is made of a single or double braid of plain, tinned, or silver-coated copper. The outer covering is made of synthetic resin (vinyl), Teflon tape, or chloroprene. This covering serves both as weatherproofing and protection from mechanical abuse.

Flexible coaxial cables are classified in four groups, namely, general purpose, high temperature, pulse, and special characteristics. The general purpose cables consist of various sizes of cables as just described. The high temperature cable is basically the same but usually has a dielectric made of Teflon, and the outer covering is made of Teflon tape and fiberglass braid which enables it to withstand increased temperatures. Pulse cables have the ability to withstand high voltages because of conductor spacing and the type of dielectric used in their construction.

The special characteristics cables are made of various materials and sizes of inner conductor, outer conductor, dielectric, and outer covering. By varying these parts, the capacitance, impedance, shielding, attenuation, voltage rating, and the ability to withstand weather and abuse are varied to fit the required qualities. With exception of the special characteristics type, these coaxial cables have an impedance of 50 to 75 ohms. The impedance of the special characteristics type is often much higher. An example is the RG-65A/U which has an approximate impedance of 950 ohms and is used as a high impedance video cable. When replacing a coaxial cable, care should be exercised to use the correct replacement, otherwise most of the advantages of coaxial cables are lost.

At frequencies near 3000 MHz, flexible coaxial cables have appreciable losses. At these frequencies, rigid coaxial cables are used with air as the dielectric. The inner conductor is supported by ceramic or polystyrene beads.

SUBSTITUTION OF PARTS

If the specified parts cannot be obtained, a temporary installation may be made using suitable substitute parts, but these parts should be replaced with the proper items as soon as they can be obtained. When making parts substitutions, special attention must be given to the following considerations:

1. Corrosion. The chemical or metallic composition of the part must be such that its use does not contribute appreciably to the danger of corrosion.
2. Strength. The strength of the substitute part must be the same, or greater than the ones prescribed. (When determining the strength, consideration should be given to the tensile, compression, and/or shear strength, as applicable to the specific use.)
3. Size. Substitute bolts and screws should be the same size as the prescribed item. If a detachable nut is to be used, a different thread may be tolerated; if a threaded hole or an anchor nut is involved, the thread must be the same as the one prescribed. In all cases, washers must have the same inner diameter as the prescribed item, but a different outer diameter or thickness may sometimes be permitted.
4. Length. Substitute screws or bolts must have a length which is sufficient for the particular installation, but must not be so long that they are in the path of any moving part. They must not be in contact with other aircraft items such as electrical wiring, hydraulic lines, and so forth.
5. Magnetic properties. Specific areas of the aircraft (for example, vicinity of such items as the magnetic compass, magnetic anomaly detection equipment, radio direction finder, or gyros) should not be changed in a manner that may cause the magnetic fields of the area to become distorted. In these areas, any substitute part must possess the same magnetic properties and characteristics as the one prescribed.
6. Style. Most items of mounting hardware are available in various styles. It is usually easy to find screws and bolts which are identical in all respect except for the type head. These parts are preferred as substitutes, provided they possess all the required special features.

7. Special features. If a bolt is to be torqued to a given value, a torque wrench which is usable with that type part and has the proper torque range must be available. If lock-wiring is required, the part must have suitable provisions.

8. Lubrication or coating. If specific instructions call for lubrication or coating of the parts, they must be followed for the substitute part as well as for the prescribed part. If no lubrication is permitted, the substitute part is not to be lubricated.

SOLDER

Two types of solder are available, the tin-lead alloy known as soft solder and the so-called hard or silver solder. Soft solder alloys permit the use of lower soldering temperatures and are therefore recommended for electronic applications. Where a joint of greater strength is required, silver solder is employed.

Most solder alloys do not liquify immediately as the temperature is increased. Ordinarily they change from the solid state to a plastic or semiliquid, and finally become completely liquid. Most tin-lead solders enter the plastic state at 358 °F and become totally liquid at various temperatures, dependent upon the individual composition. A combination of 63 percent tin and 37 percent lead has the lowest melting point (361 °F) for the tin-lead group. However, since it changes from solid to liquid without an intervening plastic state, it is susceptible to fracture from slight vibration while cooling.

(Solder is commonly referred to as 70/30, 60/40, and so on. This is the tin-lead content.)

FLUXES

All common metals are covered with a nonmetallic film, usually an oxide of the material, which prevents them from making the intimate contact so necessary for a good electrical connection. The purpose of a flux is to remove the oxide from the surfaces to be soldered, not to clean them. Flux cannot replace good cleaning methods in preparing surfaces for soldering. Without a clean, intimate contact, poor soldering techniques may result in a mechanically weak, high resistance joint, a so-called rosin joint in the case of rosin-base flux.

Solder fluxes may be divided into three general groups, rosin, organic, and chloride (sometimes called acid). The residue from the rosin-base fluxes is noncorrosive and electrically nonconductive, making them highly acceptable for use in military electronic equipment. The organic and chloride types are seldom used (sometimes even prohibited) because of their corrosiveness. Actually, only rosin-base flux is recommended for electronic applications.

Activated or intensified rosin-alcohol fluxes are permitted by MIL-S-6872 if they are noncorrosive. (For details, consult this specification.)

ORGANIC fluxes consist of mild organic acids and bases. These fluxes are almost as active as the organic salts, but their period of activity is brief due to their susceptibility to thermal decomposition. This limits corrosion and therefore may be used in applications where the soldered assembly lends itself to residue removal.

CHLORIDE type fluxes are not recommended for electronic applications.

POTTING COMPOUND

Most electrical connectors and some relays used in aircraft are potted to prevent corrosion, contamination, or arc-over between pins and terminals. Because of temperature variations throughout the aircraft, two different potting compounds are used, one is tan and the other is red. The temperature range of the potting compound can be determined from its color. The tan compound is used where the temperature under operating conditions does not exceed 87.8 °C (190 °F). The red compound is used where the temperature is higher. Should it become necessary to replace or repot a relay or connector, the potting compound used should have the same temperature range (color) as the original material. Care should also be taken to duplicate the shape of the original potting so that no installation problems will occur.

SUPPLY

There are over 1,000,000 items used by the Navy today to support its five basic programs of personnel, ships, aircraft, ordnance, and bases. Relatively small activities carry 40,000 items to support their customers, and process demands exceeding that number in range. The fact that these items are available means little unless they are positively identified in a medium understandable from the procurer, through the various supply echelons to the consumer.

One of your duties as an AQ will involve the identification of aeronautical material. Required material must be identified prior to submitting a requisition. If you submit a request with incorrect information, the wrong material may be received or the request may be rejected for lack of identification. Much confusion and unnecessary labor, expense, and waiting result when orders do not correctly identify the material required.

Positive identification of an item of supply has been accomplished when it is identified to its applicable national stock number. When the NSN is available, other required information such as application, physical characteristics, and so forth, is easily obtained by referring to the appropriate stock catalog. Those materials exempt from the federal cataloging system are exceptions to this rule.

WHERE TO LOOK

Maintenance instructions manuals (MIMs) are published by the direction of NAVAIR for each type of naval aircraft. These publications primarily contain information of maintenance significance; however, standards, specifications, and part numbers which frequently appear in the manual may aid in identifying material requirements.

An illustrated parts breakdown (IPB) is prepared by the manufacturer for each model aircraft, engine, accessory, electronic equipment, or other aeronautical equipment considered advisable by NAVAIRSYSCOM, and is printed and issued by the authority of NAVAIRSYSCOM. The IPB is designed to enable supply and maintenance personnel to identify and order replacement parts for the aircraft or equipment. All procurable assemblies and detail parts are illustrated and listed in such a manner as to make possible quick identification of assemblies and their component parts. The items are arranged continuously in assembly breakdown order with the illustrations placed as near as possible to their appropriate listing.

Naval Air Systems Command Initial Outfitting Lists (IOL), Allowance Lists (AL), and Tables of Basic Allowances (TBA), which are sometimes referred to collectively as NAVAIR allowance lists, are prepared by NAVAIRSYSCOM or the Aviation Supply Office. In all instances these lists are approved by NAVAIRSYSCOM. These lists contain the following:

1. The equipment and material (both consumable and nonconsumable) necessary to outfit and maintain units of the aeronautical organization in a condition of material readiness
2. Substantially all items used with sufficient frequency to justify their issuance to all activities maintaining aircraft or equipment for which the lists are designed
3. Information concerning stock number, nomenclature, interchangeability, and supersedures
4. A set of detailed instructions for the application and utilization of the publication
5. A table of logistic data showing the total weight and cube of all material contained in the list

Equipment parts lists catalog material according to the type of aircraft or equipment it is designed for, rather than what it is. The Aviation Supply Office (ASO) has developed a Weapon Equipment List (WEL) for most aircraft types. For example, WEL 0076 and WEL 0086 contain lists of repairable assemblies, supporting repair parts, attaching parts, loose equipment, and accessories for the A-7A and the A-4 (series) aircraft, respectively.

A WEL contains a cross-reference listing from the manufacturer's part number to the national stock number (NSN). The WEL is a comprehensive multivolume publication containing all the management data necessary for identification and procurement of items for the aircraft type covered. It also contains a list of allowance lists, major avionics equipment, and technical manuals applicable to the aircraft, and a section containing explanations of the various codes and information on how to use the publication.

Descriptive type catalogs or identification lists (ILs) catalog material by what it is, rather than by what it is used on. Raw materials, administrative supplies, tools, and the like, are cataloged in this manner. These catalogs, which have a comprehensive alphabetical index, group like items together, and thoroughly describe the items (size, weight, composition, and so forth).

As part of the federal cataloging system, each item of supply is assigned an official government name. Maintenance personnel frequently refer to material by trade name or terminology other than the official government name. Alphabetical indexes in the various stock catalogs and other publications are sequenced by the official name. To effectively utilize these publications, it is necessary to become acquainted with the proper nomenclature.

This may be more easily said than done since there are more than 20,000 uniform names which are approved for use in federal supply catalogs and probably twice that many colloquial or slang names, brand names, and obsolete names being used by maintenance personnel.

MANUFACTURER'S PART NUMBER

Normally, manufacturers of parts stamp, etch, paint, or otherwise affix a part number on each item manufactured. The use of this manufacturer's part number and the knowledge of the part's application (that is, aircraft or equipment on which used) normally lead to the positive identification of the part's nomenclature and national stock number. The part number can be ascertained to be correct by reference to the appropriate Illustrated Parts Breakdown, and the national stock number may be obtained by reference to the appropriate Master Cross Reference Listing (MCRL).

Manufacturer's part numbers are assigned by the individual company and are likely to be duplicated by other companies. Therefore, the manufacturer's part number cannot be used independently to identify an item of supply. It must be used in conjunction with the federal supply code for manufacturers (FSCM), which is a coding system of five-digit numbers assigned to establishments which are sources of supply for items procured by agencies of the Federal Government. There are FSCMs assigned to both domestic and foreign sources of supply. A complete list of these codes can be found in Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name).

FSCMs are also used to identify part numbers and specification numbers assigned by SYSCOMs, inventory managers, and other offices within the Department of Defense.

CODED NATIONAL STOCK NUMBER

Under the federal cataloging system, national stock numbers are required for all items that are subject to central inventory management within the Department of Defense. Each Navy item to be stocked under centralized inventory control is assigned a national stock number which is used in all supply management functions. This NSN is listed in all supply publications in which the item is referred.

The national stock number is a 13-digit number which furnishes positive identification of virtually all items of supply from purchase to final disposition. In addition to the 13-digit number, the Navy supply system utilizes certain code prefixes and suffixes to aid in the performance of various management functions. These codes are of significance only within the Navy and are not used during interservice transactions. Figure 2-26 describes the format of a Navy, coded national stock number for an item of supply under the cognizance of the Aviation Supply Office (ASO). The following sections further explain the national stock number.

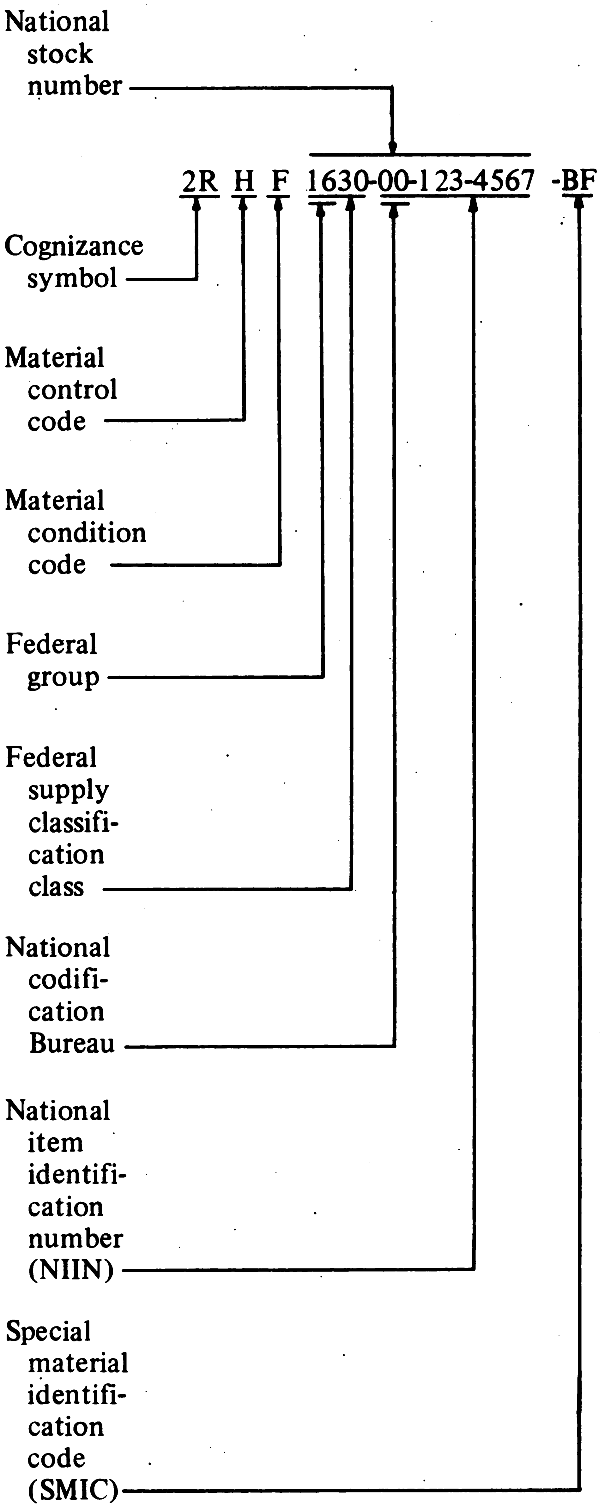
National stock number
2R H F 1630-00-123-4567 -BF
Cognizance symbol
Material control code
Material condition code
Federal group
Federal supply classification class
National codification Bureau
National item identification number (NIIN)
Special material identification code (SMIC)

Figure 2-26.—Example of a National Stock Number.

Cognizance Symbol

A cognizance symbol consists of a two-character code prefix to identify and designate the systems command, office, agency, or Navy inventory manager that exercises management control over specific categories of material. The first digit of the cognizance symbol also conveys certain accounting information to the supply system. Generally, odd numbers indicate the material is carried in the Navy stock account (NSA), while even numbers indicate it is carried in the appropriation purchases account (APA). The cognizance symbol 2R in the preceding example designates the item of supply as being APA material and under the inventory control of the ASO.

Material Control Codes

Material control codes divide inventories into segments reflecting similar demand, repairability, or other characteristics. Management techniques peculiar to various segments of material can be easily recognized at all levels of responsibility by this code. In the preceding stock number example, material control code H designates the item as repairable, subject to scheduled overhaul at designated Navy rework facilities or commercial concerns. (Defective repairable material must be returned for overhaul upon receipt of a replacement item.)

Material Condition Codes

Material condition codes classify material in terms of readiness for issue and use, or to identify action under way to change the status of material. There are presently 13 different condition codes, letters A through N (less I), which may be assigned to Navy material.

Since material condition codes apply to specific quantities of material, they do not appear in stock catalogs. They do appear on stock records and on documents which affect stock records.

National Stock Number (NSN)

The national stock number consists of the applicable four-digit classification code number from the federal supply classification (FSC), plus a hyphen and the applicable nine-digit national item identification number (NIIN).

FEDERAL SUPPLY CLASSIFICATION (FSC).—The federal supply classification is a four-digit numerical code which occupies the first four digits of the NSN. The purpose of the FSC is to identify stock items by commodity or descriptive category. The first two digits of the FSC is known as the FSC group and classifies stock into major or broad categories. There are potentially 99 FSC groups, of which 76 are currently being used. The second two digits of the four-digit code further divide the groups into four-digit classes.

NATIONAL ITEM IDENTIFICATION NUMBER (NIIN).—The national item identification number is a nine-digit number which identifies each item-of-supply used by the Department of Defense (DOD). The NIIN indexes or relates to identification data (information) which make an item-of-supply different (as far as DOD is concerned) from every other item-of-supply. The amount and type of identification data depends on the item and its intended use. Although the NIIN is part of the NSN, it is used independently to identify an item. Except for identification lists, most federal supply catalogs are arranged in NIIN order.

Special Material Identification Code (SMIC)

The special material identification code (SMIC) is a two-digit code suffixing the national stock number. Currently, ASO is using the SMIC to identify items to aircraft models, engine models, certain commodities (photographic, meteorological, and so forth), and special projects or programs.

SHIPPING AND RECEIVING

Material is frequently returned to the supply department from station departments, ships and fleet aviation units. Material may be returned because it is excess to the needs of the consumer, or because it is unfit for use and is potentially repairable or has salvage value.

Material that is in excess of the requirements of a consumer activity is turned in to the supply department on a Single Line Item Release/Receipt Document (DD Form 1348-1). The material should be accompanied with at least four copies of DD Form 1348-1.

The material is normally received by the receiving operations section. A copy of DD Form 1348-1 is forwarded to the receipt processing section for the establishment of an open-order file. The material is forwarded to the screening and identification component of the storage branch.

The screening and identification component examines the material to ensure that it is properly identified and is fit for reissue in all respects. When a screening and identification component of the storage branch is not established, the material is held in receiving during the screening process.

When it becomes necessary to replace exchangeable material, material accountability recoverability coded D, E, R, or L, the old part is turned in for repair. Under the Naval Aviation Maintenance Program (NAMP), procedures have been developed to control repairable material through the repair process and to provide for its ultimate return to the supply system. The Supply Support Center of the supply department exercises control over the repairable items while they are in the repair process, and coordinates the physical movement of such items. The VIDS/MAF, prepared by the maintenance personnel, is used as the control and turn-in document.

When material is received from supply, it should be inspected carefully. Physical damage can occur between the time it was certified to be RFI (ready for issue) and the time it is received. Also, it should be verified that the item is actually the one needed, and that any required modifications or service changes have been incorporated. If the item consists of more than one assembly, determine if all are included in the shipment. These visual checks will often save a great amount of work and time in the accomplishment of the maintenance task.

SUMMARY

This chapter presented you with some of the considerations that you should exercise with regard to handtools and materials used in the maintenance of Navy aircraft. The following is a summary of the important points in the chapter.

HANDTOOLS—Small portable or fixed power tools commonly available in electronics maintenance shops, or used by electronic maintenance personnel during work on aircraft, as well as those normally classified as nonpowered tools.

Handtools may be of a general type—center punch, pin punch, screwdriver, chisel, grinder, drill, pliers, wrenches, and so forth.

Handtools may be of a special type—nonmagnetic, insulated, torque wrenches, relay tools, wire and cable tools, safety wiring pliers, wire and cable strippers, crimping tools, and so on.

SAFETY—One of the primary considerations in the use of handtools is safety. The following precautions are stressed:

1. Use the proper tool for its designed function, and use it in the proper manner.
2. Maintain all tools in proper working order and in a safe condition. Sharpen or replace dulled cutting tools, replace broken or defective tools, and protect tools from damage while in use or in storage.

TOOL ACCOUNTABILITY—The tool control program (TCP) provides for instant inventory, silhouetted tool containers. The program is designed to reduce initial outfitting, eliminate FOD, reduce pilferage and tool replacement cost in addition to other benefits.

Shore-based squadrons with a central toolroom have the following responsibilities.

1. Maintaining tools on hand for temporary checkout and replacement for broken tools
2. Initiating requests for required tools
3. Maintaining custody receipts and checkout slips for "one-of-a-kind" tools, accountable IMRL items such as power tools, special tools, and in some cases general electronics test equipment
4. Maintaining tool box inventory records and records specifying to whom tools and tool boxes are issued

5. Inventorying tool boxes
6. Marking all handtools

Squadrons with carrier aircraft assigned rarely have a toolroom. The toolroom responsibilities in these situations are normally divided among the various work center supervisors.

Both situations require that a tool box inventory be performed periodically. This requires that tools be marked, that an inventory record be maintained, and that shortages be reported.

HARDWARE AND CONSUMABLE MATERIALS—Hardware and material are used for both the installation of equipment and the repair of installed equipment. Proper parts and material should be used. Substitutions should be satisfactory in all respects.

SUPPLY—National stock numbers (NSNs) are the primary means of identifying supply items within the Department of Defense. The national stock number is a 13-digit number that furnishes positive identification of virtually all items of supply from purchase to final disposition.

Other places to look for identification of parts are:

1. Maintenance instructions manuals (MIMs)
2. Illustrated parts breakdown (IPB)
3. NAVAIR allowance lists
4. Weapon equipment lists (WELs)
5. Manufacturer's part number, used in conjunction with the federal supply code for manufacturers (FSCM)
6. Descriptive type catalogs or identification lists (ILs)

CHAPTER 3

SERVOSYSTEMS

As an Aviation Fire Control Technician, you will encounter various types of servosystems. The particular type—electromechanical, electrohydraulic, hydraulic amplidyne, pneumatic, to name a few—will depend upon the type of load for which it was designed. One of the primary applications in your area of endeavor is the control of radar antennas from a remote control station. We will discuss some methods of antenna control later in this chapter.

It is not intended that this chapter provide a detailed presentation of any one servosystem. Instead, the intent is to acquaint you with the basic systems, to identify their essential components, and to explain the function of each component. For the details concerning the theory and operation of a particular system, you should refer to the applicable technical manuals for that system. In addition, if you have not done so, you should review the basic theory of synchros and servomechanisms as discussed in Module 15 of the Navy Electricity and Electronics Training Series (NEETS), NAVEDTRA 172-15-00-80. After this review, you will be ready for our discussion of basic servomechanisms.

BASIC SERVOMECHANISMS

The essential components of a servomechanism are a data transmission system, a servocontrol amplifier, and a servomotor. These components are shown in the block diagram of figure 3-1 and are discussed in the following paragraphs.

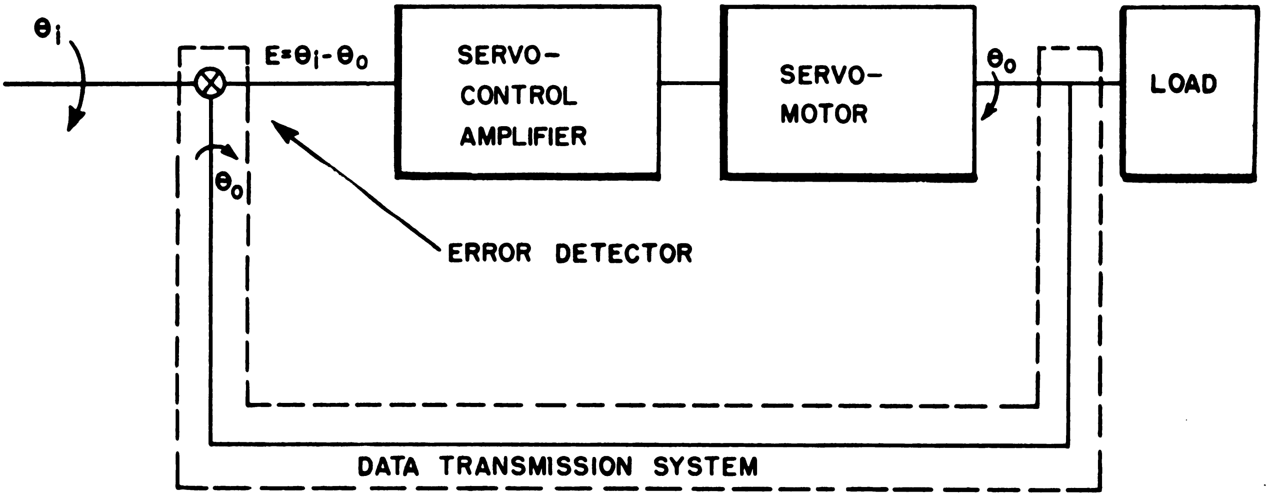

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Figure 3-1.—Simplified block diagram of a servomechanism.

The functions of the data transmission system are as follows:

1. To measure the servo output
2. To transmit or feedback the signal, which is proportional to the output, to the error detector (a differential device for comparing two signals)
3. To compare the input signal with the feedback signal
4. To transmit to the servoamplifier a signal which is proportional to the difference between the input and output signals

The signal obtained by comparing the servo input and output is called the servo error, and is represented by the symbol E. Figure 3-1 shows that the servo error (E) is the difference between the input (θ_i) and the output (θ_o). This is stated mathematically as $E = \theta_i - \theta_o$.

In many servosystems, the physical location of the servo input device and output device are remotely located from each other and may also be remotely located from the servoamplifier. This requires some means of transmitting the output information back to the device receiving the input command and transmitting the servo error to the servoamplifier. This system of transmission as well as the comparing device (called an error detector) is part of an overall data transmission system. We discuss data transmission to some extent later in this chapter. The function of the servoamplifier is to receive the error signal from the error detector, amplify it sufficiently to cause the output device to position the servo load to the commanded position, and to transmit the amplified signal to the servomotor.

The servomotor functions to position the servo load. The motor must be capable of positioning the load within a response time based on the requirements of the system.

ERROR DETECTORS

The component of the data transmission system that compares the input with the servomechanism output is the error detector. An error detector can be either a mechanical or an electrical device. A simple form of a mechanical error detector is the differential. However, in aircraft weapons systems, most error detectors are electrical devices because of their adaptability to widely separated or remotely installed components. Most of the electrical devices used are of either the potentiometer (resistive) or one of several magnetic devices.

Electrical error detectors may be either ac or dc devices, depending upon the requirements of the servosystem. An ac device used as an error detector must compare the two input signals and produce an error signal of which the phase and amplitude will indicate both the direction and the amount of control necessary to accomplish correspondence. A dc device differs because the polarity of the output error signal determines the direction of the correction necessary.

Error detectors are also used extensively in gyro stabilized platforms and rate gyros. In the stabilized platform, synchros are attached to the gimbals. Thus, any movement of the platform around the gyro axes is detected by the synchro and the error voltage is sent to the appropriate servosystem.

In rate gyros, an E-transformer (discussed later) is commonly used to detect gyro precession. It is extremely sensitive to very slight changes, but its movement is limited to a very small amount. Thus, it is extensively used with constrained gyros.

POTENTIOMETER

Potentiometer error detector systems are generally used only where the input and output of the servomechanism have limited motion. They are characterized by high accuracy, small size, and the fact that a dc or an ac voltage may be obtained as the output. Their disadvantages include limited motion, a life problem resulting from the wear of the brush on the potentiometer wire, and the fact that the voltage output of the potentiometer changes in discrete steps as the brush moves from wire to wire. A further disadvantage of some potentiometers is the high drive torque required to rotate the wiper contact.

An example of a balanced potentiometer error detector is shown in figure 3-2. As we have indicated, the purpose of the circuit is to give an output error voltage which is proportional to the difference between the input and output signals.

The command input shaft is mechanically linked to R1 and the load is mechanically linked to R2. An electrical source of 115 volts ac is applied across both potentiometers.

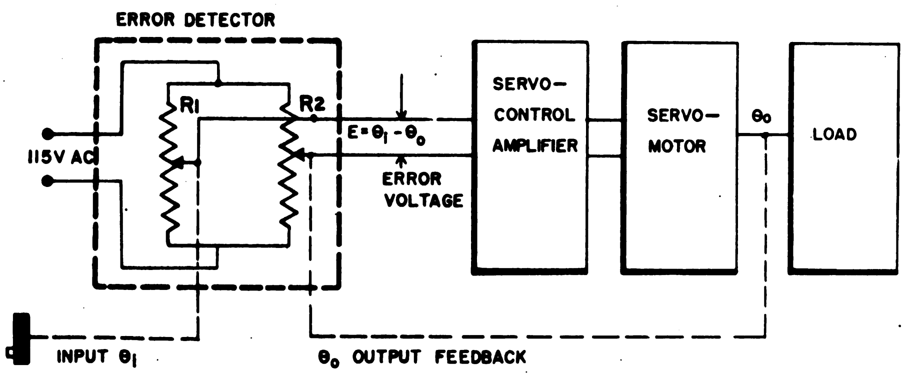

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Figure 3-2.—Balanced potentiometer error detector system.

When the input and output shafts are in the same angular position, they are in correspondence and there is no output error voltage. If the input shaft is rotated, moving the wiper contact of R1, an error voltage is developed and applied to the control amplifier. This error voltage is the difference of the voltages at the wiper contacts of R1 and R2. The output of the amplifier causes the motor to rotate both the load and the wiper contact of R2 until both voltages are equal. When equal, there is no output error voltage.

Figure 3-2 illustrates R1 and R2 grouped together. In actual practice the potentiometers may be positioned remotely from each other, with R2, the output potentiometer, being located at the output shaft or load. The remote location of one of the components does not remove it from being a part of the error detector.

E-Transformer

A type of magnetic device used as an error detector is the E-transformer. Its application is useful in systems that do not require the error detector to move through large angles. A simplified drawing, which is one of several possible devices in this category, is shown in figure 3-3.

The primary excitation voltage is applied to coil A on the center leg of the laminated core. The coupling between coil A and the secondary windings, coils B and C, is controlled by the armature which is displaced linearly by the input signal. When the armature is positioned so that the coupling between the windings is balanced (null), the output voltage is minimum because of the series-opposing connections of the secondary windings. The phase of the output voltage on either side of the voltage null differs by 180°, and by proper design of the transformer, the amplitude can be made proportional to the displacement of the armature from its null voltage position. This type of error detector has the advantages of small size and high accuracy, but has the disadvantage of permitting only limited input motion.

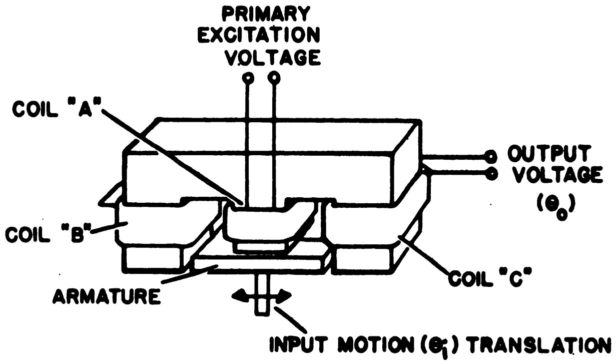

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Figure 3-3.—E-transformer error detector.

Control Transformer

Synchros have been developed to a point of relatively high accuracy, low noise level, reasonably small driving torques, and long life. These qualities also apply to synchro control

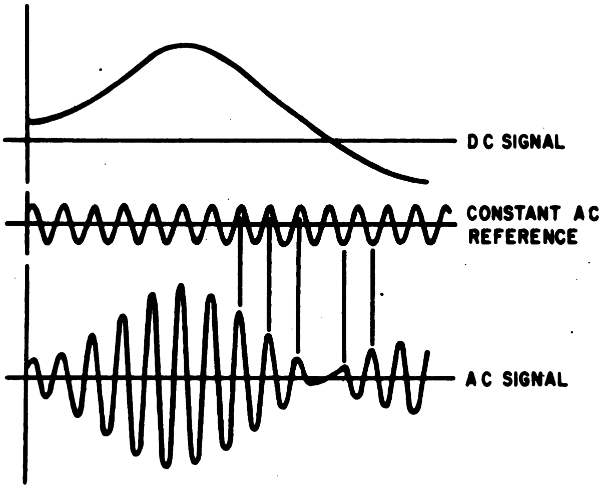

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Figure 3-4.—AC modulated with the servo error.

transformers. A primary advantage of the synchro control transformer over other types of error detectors is its unlimited rotation angle; that is, both the input and the output to the synchro control transformer may rotate through unlimited angles. Among the disadvantages of synchros (including the synchro control transformer) are the large size necessary to maintain high accuracy, the power consumed, and the fact that the output supplied to the servocontrol amplifier is always ac modulated with the servo error.

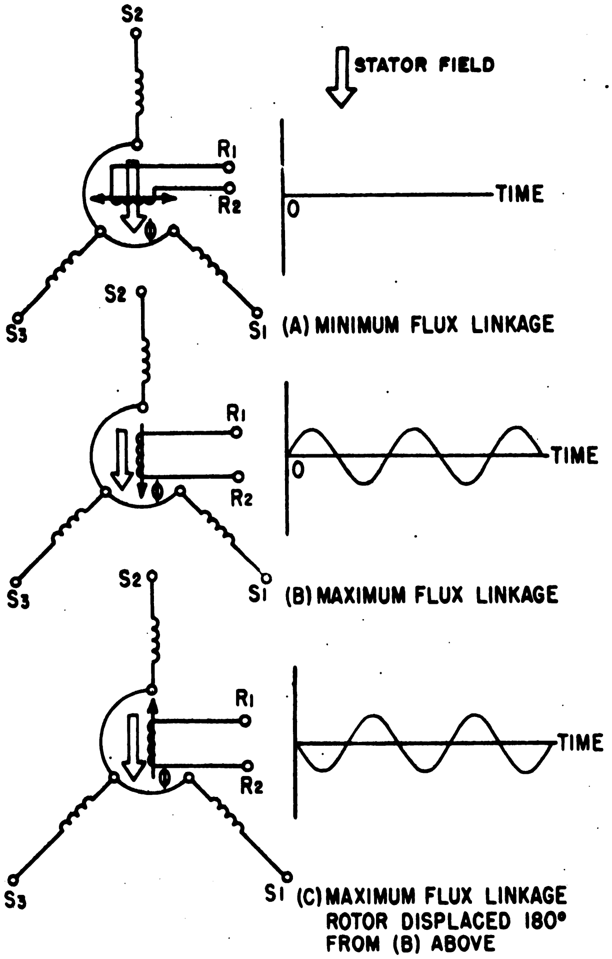

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Figure 3-6.—Induced voltage in synchro control transformer rotor.

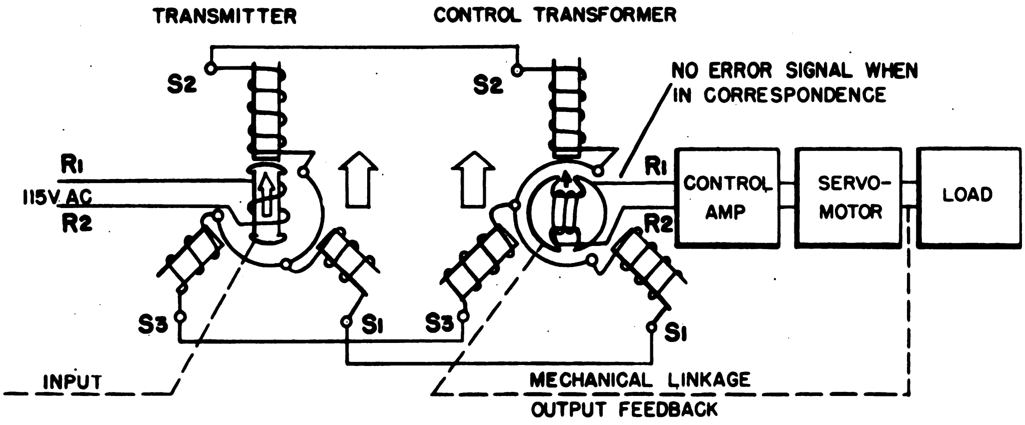

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Figure 3-5.—The control transformer as an error detector.

Alternating current may be used if the two following conditions are met:

1. The frequency of the ac used must be greater than the maximum frequency response of the measuring devices used.
2. If negative values of the variables are allowed, the devices used must be phase-sensitive.

Figure 3-4 shows a dc signal and the same function represented by an ac voltage. The instantaneous value of the ac signal does not indicate the value of the function, but the average value of the ac signal may be used to represent the value of a function. If the ac signal is the input to a servo motor, for example, the motor must not attempt to follow every variation of the ac signal, but must follow the average value. The second condition is essential because a negative ac signal does not exist. However, negative values can be indicated by a change in phase of the signal. Note that in figure 3-4, during the period when the dc signal is positive, the positive peaks of the ac signal correspond to the positive peaks of the ac reference; but during the period when the dc signal is negative, the positive peaks of the ac signal correspond to the negative peaks of the reference; i.e., the signal is 180° out of phase with the reference. Alternating-current servomotors, which will rotate in one direction when the input signal is in phase with a reference voltage, and in the other direction when the signal is out of phase with the reference voltage, are available.

A synchro data transmission system is comprised of a synchro transmitter, a synchro control transformer, and in some cases a differential transmitter for additional servo inputs. The synchro transmitter transforms the motion of its shaft into electrical signals suitable for transmission to the synchro control transformer, which comprises the error detector (fig. 3-5).

The stator of the transmitter consists of three coils spaced 120 electrical degrees apart. The voltage induced into the stator windings is a function of the transmitter rotor position. These voltages are applied to the three similar stator windings of the synchro control transformer. The voltage induced in the rotor of the synchro control transformer depends upon the relative position of this rotor with respect to the direction of the stator flux.

The variation of the synchro control transformer output voltage as a function of the rotor position relative to an assumed stator flux direction is shown in figure 3-6. While there are two positions of the rotor, 180° part, where the output voltage is zero, only one corresponds to a stable operating position of the servo.

When a synchro differential transmitter is used for additional inputs to the servosystem, it is connected between the synchro transmitter and the synchro control transformer (fig. 3-7). When

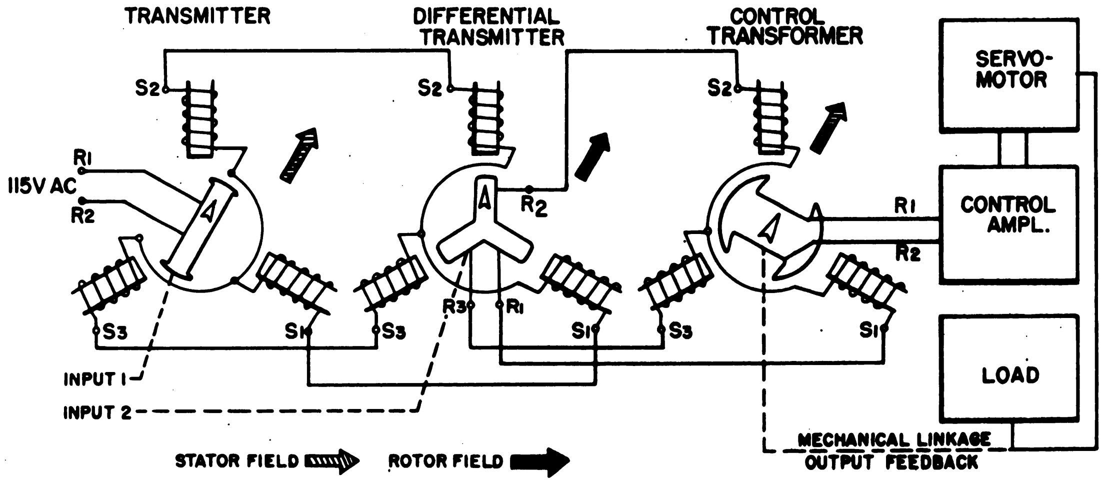

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Figure 3-7.—Synchro differential transmitter used for additional input.

the synchro differential rotor is in line with its stator windings, the differential transmitter acts as a one-to-one ratio transformer and the voltages applied to the synchro control transformer are the same as the voltages from the synchro transmitter. If the synchro differential transmitter rotor is displaced by a second input, the voltages from the synchro transmitter to the control transformer are modified by the synchro differential transmitter by the amount and direction of its rotor displacement. Thus, the two inputs are algebraically added and fed to the synchro control transformer as a single input.

Fluxgate

A fluxgate element may be used to drive or excite a control transformer and is usually used in compass systems. The fluxgate operates on the principle of using the earth's magnetic field to produce a second harmonic current flow in the element which in turn produces a voltage in the stator windings of the control transformer that is in direct proportion to earth's magnetic north. Because it is desirable to use only the horizontal component of the earth's field, a gyro is used to hold the element level with the earth's surface, or the element is suspended by a spring and uses the properties of a pendulum to maintain a horizontal position. The assembly is rigidly mounted to the aircraft and turns in an azimuth as the aircraft turns.

MULTIPLE-SPEED DATA TRANSMISSION SYSTEMS

The static accuracy (how accurately the load is controlled) of a servomechanism is frequently limited only by the accuracy of the data transmission system. The accuracy of the data transmission system may be increased considerably by employing a multiple-speed data transmission system along with a 1-speed system. The error-detector elements of the multiple-speed transmission system rotate at some multiple of the shaft being controlled, while the elements of the

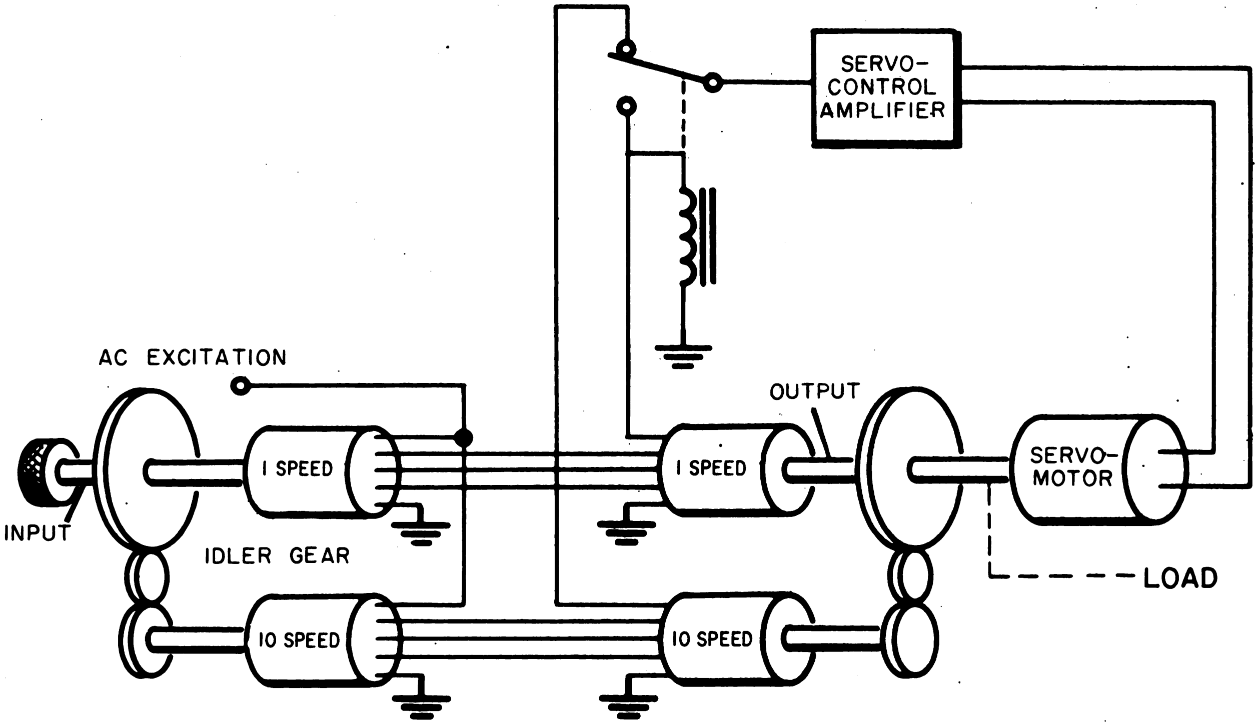

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Figure 3-8.—Dual-speed data transmission system.

1-speed transmission system operate one-to-one with respect to the controlled shaft.

The schematic diagram of a multiple- and a 1-speed system is shown in figure 3-8. (If a system can transmit data at two different speeds, it is referred to as a dual-speed system.) In this example, if the input shaft turns through 1°, the 1-speed transmitter also is rotated 1° while the multiple-speed unit is rotated 10°. The synchro control transformer associated with each of these transmitters is geared in similar ratios with respect to the servo output shaft. A 1° error between the position of the input and output shafts, therefore, produces a relative rotor displacement of 1° in the 1-speed synchros, and 10° in the multiple-speed synchros. If the relation between the rotor displacement and output voltage is linear, the error signal from the multiple-speed system is 10 times that from the 1-speed system. This amplification of the error signal in the data transmission link reduces the signal amplification required in the servocontroller. If the synchro has an inherent error of 0.1° with respect to its own shaft, the consequent servo error introduced by a 1-speed data transmission system will be of corresponding magnitude; but the consequent servo error introduced by a 10-speed data transmission system will be only one tenth as great, or 0.01°.

A disadvantage of using a multiple-speed error detector lies in the possibility of the system falling out of step and synchronizing in a position differing from the correct position by an integral number of revolutions of the multiple-speed synchro. In the example shown in figure 3-8, if the output shaft were held fixed and the input shaft rotated 36°, the 10-speed synchro transmitter would turn one complete revolution. At this point the error signal from the multiple-speed error detector would be zero. If the output shaft were then released, the system would operate in a stable fashion with a 36° error between the input and output shafts. The purpose of using a 1-speed error detector, along with the multiple-speed detector, is to prevent this ambiguous synchronization.

An error signal selector circuit is provided which switches control of the servo to the 1-speed data transmission system whenever the servo error becomes large enough to permit the multiple-speed system to synchronize falsely.

The simplest device imaginable that could control an error-selector circuit is shown in figure 3-8. It is essentially a single-pole, double-throw relay actuated by the output of the 1-speed error detector. The relay is shown in the deenergized position. When the output of the 1-speed synchro is high, the relay is energized and the 1-speed circuit controls the servomotor. When the output is low, the relay opens and the 10-speed synchro controls the circuit. Keep in mind that the synchro output is high only when there is a large error.

The relationship of the coarse (1-speed) synchro output and the fine (10-speed) synchro output is shown in figure 3-9(A). The shaded

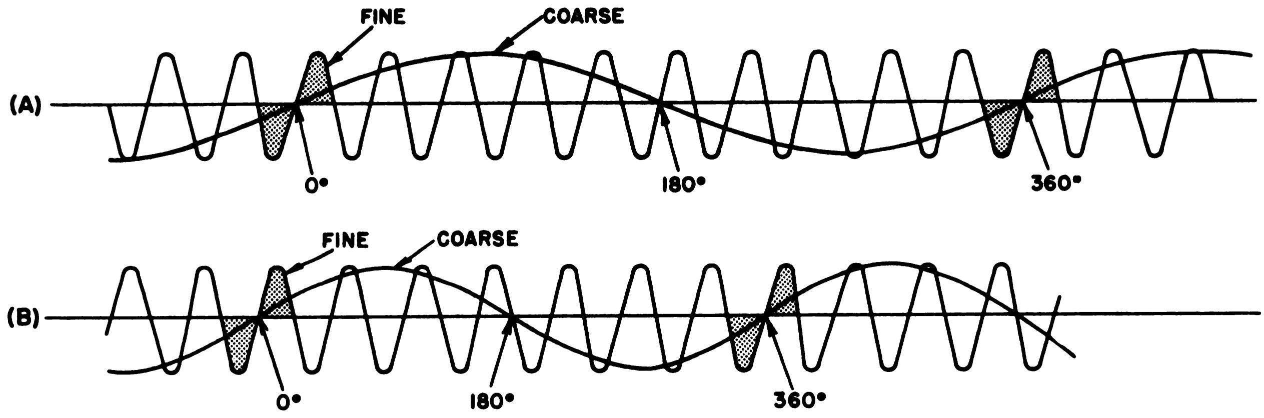

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Figure 3-9.—Phase relationships of fine and coarse synchro voltages; (A) single-speed and 10-speed; (B) single-speed and seven-speed.

portion represents the area where control can be switched from 1-speed circuit to the 10-speed circuit. With the selector circuit shown, it is still possible to have a single ambiguous synchronizing point. This point is at the 180° position of the 1-speed (coarse) synchro. At this point the 1-speed (coarse) and 10-speed (fine) shafts are nulled (but are 180° out of phase) and control is switched to the 10-speed circuit.

One way of eliminating this false synchronization position is to drive the multiple-speed synchro at any odd multiple of the 1-speed synchro. Figure 3-9(B) shows the phase relationship of a 1-speed and 7-speed system. Although there is still a null of both synchros at the 180° position of the 1-speed synchro, their outputs are in phase. This position is an unstable one and the servo will not remain at this point.

The system illustrated in figure 3-8 is not found in operating equipment due partly to the load the relay places on the 1-speed synchro. In actual practice, the relay could be controlled by an electronic circuit operated by the synchro voltages. A method commonly used feeds the outputs of the synchros to an electronic circuit biased so that the fine-synchro voltage is not used when the coarse-synchro voltage is high. This method does not require a relay.

The disadvantage of using multiple-speed error detectors is the need of an additional synchro system and switching circuit if false synchronization is to be avoided. The increased servo accuracy resulting from the amplification of the error signal and the effective reduction of inherent synchro errors account for the wide use of these multiple-speed data transmission systems.

SERVOCONTROL AMPLIFIERS

Earlier, we pointed out the fact that the output of an error detector (error voltage) can be fed to a servocontrol amplifier. This type of signal is small in amplitude and requires sufficient amplification to allow actuation of a prime mover. In addition to amplification, the servocontrol amplifier must, in some cases, transfer the error signal into suitable form for controlling the servomotor or output member. It may also include provisions for special characteristics necessary to obtain stable, fast, and accurate operation.

Servoamplifiers used in aircraft weapons systems are limited to electronic and magnetic types. The operation and explanation of electronic amplifiers and their circuits are covered in *Basic Electronics*, Vol. II, NAVEDTRA 10087 (Series).

In addition to the requirements of basic amplifiers, servoamplifiers must also meet certain additional requirements as follows:

1. A flat gain versus frequency response for a frequency well beyond the frequency range used
2. A minimum of phase shift with a change in level of input signal (Zero phase shift is desired but a small amount can be tolerated if constant.)
3. A low output impedance
4. A low noise level

Servoamplifiers may use either ac or dc amplifiers or a combination of both. The application of dc amplifiers is limited by such problems as drift and provisions for special bias voltages needed in cascaded stages. Drift, a variation in output voltage with no change in input voltage, can be caused by a change in supply voltage or a change in value of a component. Consequently, many servoamplifiers use ac amplifiers for voltage amplification. We discuss amplifiers in greater detail later in this chapter. For the present, let us continue by discussing modulators.

MODULATORS

As pointed out previously, ac amplifiers are more satisfactory for amplifying an error signal. They do not need well-regulated power supplies and costly precision components. However, some aircraft weapons systems utilize a dc voltage for an error signal. The dc error voltage may be changed to an ac signal by the use of a modulator (sometimes called a chopper). Modulator circuits used in servocontrol amplifiers must be phase sensitive and produce an ac output signal whose amplitude is proportional to the dc input signal and whose phase is indicative of the polarity.

Vibrator Modulators

A modulator may be either an electromechanical vibrator or an electronic circuit. An example of a vibrator is shown in figure 3-10.

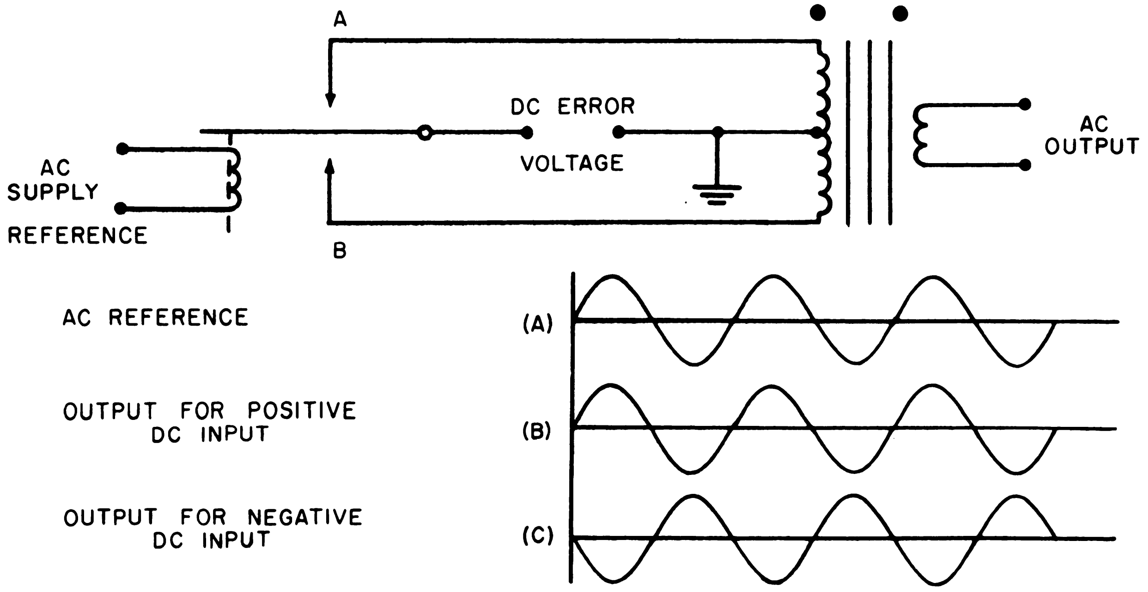

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Figure 3-10.—Vibrator modulator.

An ac supply voltage is employed to vibrate the contacts of the vibrator in synchronism with the supply voltage. The dc error voltage is applied to the center contact of the vibrator. Assume that the reference voltage will cause the center arm to contact point A during the first half cycle, and point B during the second half cycle. The output is represented by waveform B if the error voltage is positive, and by waveform C when the error voltage is negative.

Electronic Modulator

An example of an electronic modulator circuit is shown in figure 3-11. The circuit shown is a diode ring modulator and works by causing a changing current to flow through one-half of the primary of transformer T2 and then through the other half at a 400-hertz rate. Each half-cycle of changing current produces a half-cycle of sinusoidal output voltage. The phase of this output voltage compared to the 400-hertz carrier depends upon the direction of current through each primary half.

Diodes CR1 and CR4 are forward biased when the dc control voltage is positive. Diodes CR2 and CR3 are forward biased when the dc control voltage is negative.

Therefore, when two of the diodes are forward biased by the dc control voltage, the other two are back biased and cut off. As long as the

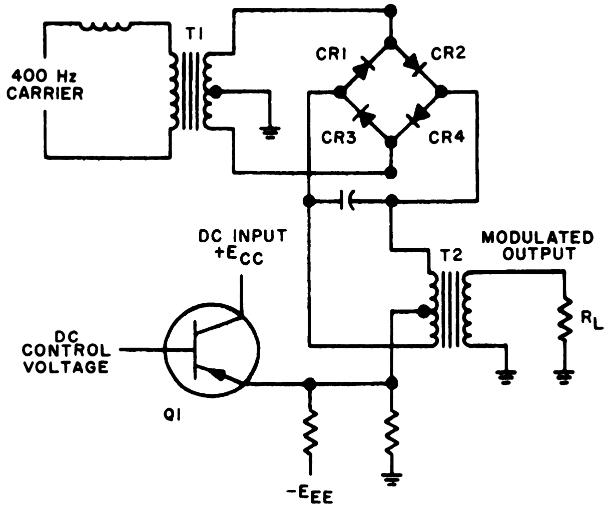

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Figure 3-11.—An electronic modulator.

instantaneous amplitude of the carrier voltage is less than the dc control voltage, the cutoff diodes remain back biased, and the current flows through one of the conducting diodes and through one of the half windings.

When one of the back biased diodes becomes forward biased (the amplitude of carrier voltage exceeds the dc control voltage), the diode conducts. This interrupts the current flowing through the half winding. The result is that the output voltage amplitude is clipped at the value it had when the current was interrupted.

The capacitor connected across the primary of T2 filters any high frequency components associated with the clipped half-cycle of the sine wave so that a nearly sinusoidal output half-cycle occurs. The output's amplitude is approximately equal to the output voltage at the time of clipping.

The capacitor operates by coupling the high frequency components of the clipped voltage through the nonconducting half windings. The high frequency components are canceled because they produce currents which flow in opposite directions in both halves of the center tapped primary windings; that is, they produce magnetic fields which cancel each other.

Therefore, the amplitude of each half-cycle of the 400-hertz carrier voltage is modulated by the dc control voltage. The polarity of the control voltage determines the phase of the modulated carrier voltage output relative to the unmodulated carrier voltage input. This is done as a result of the direction of current flow through the half winding. This direction depends upon which diode is forward biased as a result of the polarity of the dc control voltage.

PHASE DETECTORS

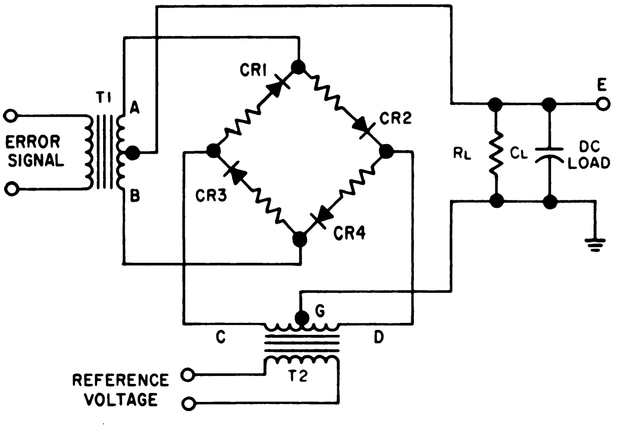
We have stated that an ac amplifier has inherent advantages over a dc amplifier, that a dc error voltage can be changed into an ac signal, and the ac signal can be amplified and applied to an ac servomotor. However, some systems utilize dc servomotors which necessitates converting the ac signal to dc. To accomplish this, a phase detector, sometimes referred to as a demodulator, is used.

Bridge Phase Detectors

Figure 3-12 displays a phase detector using a bridge circuit. With no error input signal and only the reference voltage applied, CR1 and CR2 would conduct in series when point C is on its positive half-cycle. When point C is on its negative half-cycle, CR3 and CR4 would conduct in series. Assuming the drops across the diodes and resistances to be equal, points A and B would be at ground potential on both half-cycles and the output voltage would be zero.

When an error signal is applied to the bridge in phase with the referenced voltage and points A and C are both on their positive half-cycle, electron flow will be from point G on the reference transformer T2; to point D; through CR2 to point A; from point A to the center tap on T1; and to E through R_L to G. On the next half-cycle, both points A and C will change polarity and the electron flow will be from point G to point C, through CR3 to point B, through T1 to the center tap, to the right to point E, and through R_L to G. On both half-cycles of reference and error voltage, the electron flow was down through R_L to ground, developing a negative dc output voltage.

If the error signal is applied out of phase with the reference voltage and positive at points A and D, electron flow will be from point G up through R_L, left to the center tap of T1, down to point B, through CR4, down to point D, and left to



222.14

Figure 3-12.—Bridge phase detector.

point G. On the next half-cycle, both points A and D will have changed polarity; thus, electron flow will be from G up through R_L to the center tap of T1, up to point A, through CR1 to point C, and right to the center tap to point G. On both half-cycles of the error and reference voltages, electron flow was up through R_L, developing a positive voltage output at point E. The magnitude of the dc produced at point E in both instances was dependent on the amplitude of the ac error signal and the polarity of the dc was dependent on the phase of the ac error signal. C_L is used to filter the pulses and provide smooth dc.

Triode Phase Detectors

A phase detector that uses npn transistors and also provides amplification of the error signal in addition to phase detection is depicted in figure 3-13. In this circuit, the collectors of the transistors are supplied with the ac reference voltage in such a manner that the collector voltages are in phase. For the purpose of explanation, assume that no error signal is present at T2. When the collectors of Q1 and Q2 are positive, the two transistors conduct equally. The collector current that flows sets up magnetic fields in the dc motor exciter windings that are equal and opposite; therefore, the fields cancel and produce no output. When the collector voltages are on a negative half cycle, C1 and C2 discharge through their respective exciter windings to maintain a constant direct current through the windings.

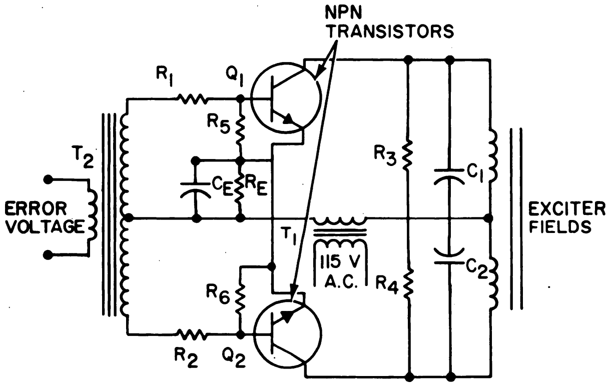


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Figure 3-13.—Triode phase detector.

If an error signal is introduced into the primary of T2 with a phase relationship that causes the base of Q1 to be positive at the same instant that the collector of Q2 is positive, the following conditions exist:

1. On this half cycle the conduction of Q1 is increased above its no error signal condition.
2. The heavier collector current causes a stronger field to be created in the upper exciter winding.
3. At this same instant, since the base of Q2 is on a negative half cycle, its average conduction is reduced to a level below that of its no error signal condition.
4. The lower level of collector current causes a weaker field to be produced in the lower exciter winding.
5. Since the magnetic fields produced in the exciter windings are no longer of equal amplitude, they no longer cancel each other.
6. The exciter produces an output voltage of a polarity controlled by the polarity of the resultant field and of an amplitude controlled by the relative strength of this resultant field.
7. The exciter output causes the proper mechanical actions necessary to reduce the amplitude of the error to zero.
8. As the error signal is reduced to zero, the current conduction through Q1 and Q2 is again balanced. Also the exciter fields are equal and opposite, canceling each other, reducing the exciter output to zero, and stopping the mechanical action. Resistors R1 and R2 prevent excessive base current when the error angle is large.

SPECIAL CIRCUITS

It has been shown how a servocontrol amplifier may have provisions for changing a dc error signal to an ac signal, and how an ac error signal may be detected to supply a dc voltage to a servomotor or controller. In the following paragraphs, other special amplifier circuits are discussed.

Two-Stage Dc Servocontrol Amplifier

If somewhat more power is required by the servomotor than can be supplied by the servoamplifier (fig. 3-13), a push-pull dc amplifier can be inserted between the phase-sensitive transistors and the servomotor. In the schematic diagram (fig. 3-14), the output of the phase detector transistors is now taken across the parallel RC networks in the collector circuit.

The bias source, E_{cc}, for the dc amplifier is connected with its positive terminal on the base side. This positive voltage subtracts from the highly negative voltage across the capacitor to give a resulting negative voltage which allows the transistor to operate on the linear portion of its characteristic curve.

When there is no signal input from the error detector, the collector currents of the phase-sensitive rectifiers are equal. The outputs of Q1 and Q2 are applied to the base of Q3 and Q4, respectively. Equal output from Q1 and Q2 causes equal currents to flow in Q3 and Q4. With R5 and R6 equal in resistance and current, the voltage across the motor is zero. Consequently, the motor does not turn.

For an analysis of a signal output from the error detector, assume that the error signal makes the base of Q1 positive and the base of Q2 negative. The collector current of Q1 increases and the collector current of Q2 decreases. An increasing collector current in Q1 increases the charge on capacitor C1 and conversely a decreasing collector current in Q2 decreases the charge on capacitor C2. As a result of the change in error signal, the voltage on the base of Q3 is now more negative than the voltage on the base of Q4. This increased negative voltage on the base of Q3 decreases its collector current and the voltage e3 decreases. The decreased negative voltage on the base of Q4 increases its collector current and the voltage e4 increases. As a result, a voltage difference appears across the motor armature and the motor rotates.

When the output signal from the error detector reverses in phase, the sequence of events that follow causes the motor to reverse its direction of rotation.

Magnetic Amplifiers as Servocontrol Amplifiers

The servomotor used in conjunction with the magnetic amplifier shown in figure 3-15 is an ac type. The uncontrolled phase may be connected in parallel with transformer T1 by utilizing a phase shifting capacitor, or it may be connected to a different phase of a multiphase system. The controlled phase is energized by the magnetic amplifier and its phase relationship is determined by the polarity of the dc error voltage.

The magnetic amplifier consists of a transformer (T1) and two saturable reactors, each having three windings. Note that the dc bias current flows through a winding of each reactor and the windings are connected in series-aiding. This bias current is supplied by a dc bias power source. A dc error current also flows through a winding in each reactor; however, these windings are connected in series-opposing.

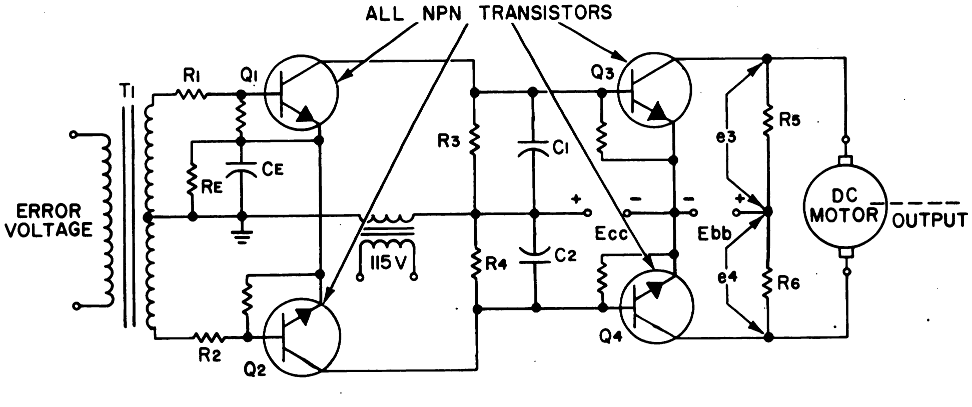

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Figure 3-14.—Two-stage dc servocontrol amplifier.

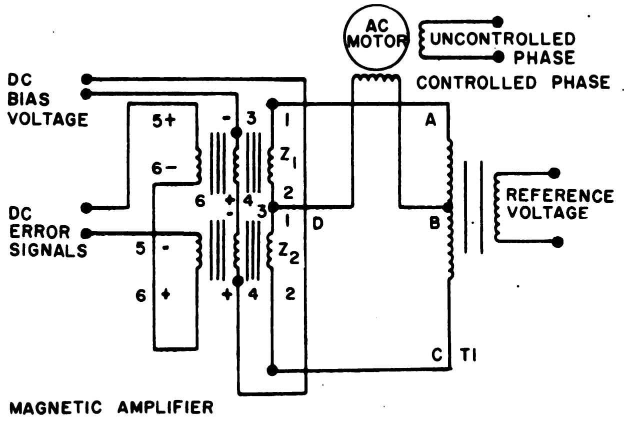

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Figure 3-15.—Magnetic amplifier servocontrol amplifier.

The reactors Z_1 and Z_2 are equally and partially saturated by the dc bias current when no dc error signal is applied. The reactance of Z_1 and Z_2 are now equal, resulting in points B and D being at equal potential. There is no current flow through the controlled phase winding.

If an error signal is applied causing the current to further saturate Z_2, the reactance of its ac winding is decreased. This current through Z_1 tends to cancel the effect of the dc bias current and increase the reactance of its ac winding. Within the operating limits of the circuit, the change in reactance is proportional to the amplitude of the error signal. Hence, point D is now effectively connected to point C causing motor rotation. Reversing the polarity of the error signal causes the direction of rotation to reverse, since point D is effectively connected to point A.

The basic magnetic servoamplifier discussed above has a response of approximately 6 to 20 Hz. In some applications this delay would be excessive, creating too much error. However, this delay can be reduced to about 1 Hz by using special push-pull circuits.

Amplifier Integrator

A servosystem in a steady state condition will have a constant positional displacement between input and output, which is called the error. The only way to reduce this error is to increase the drive torque. Thus, a new signal must be introduced that is related to the error. The error is not changing; therefore, it cannot be a derivative signal, nor can it be proportional to the error, because it would then decrease as the error decreases and a new condition would be met without removing the error. The only way left is to produce a signal proportional to the integral of the error. Then if a torque proportional to the time integral of the error is added to the normal torque which is proportional to the error, it can be seen that the error will eventually be reduced to zero. A circuit that is used for this purpose is called an amplifier integrator.

A simple and commonly used integrator consists of two circuit elements: a resistor and capacitor. (See fig. 3-16.) The voltage across the capacitor is proportional to the integral of the charging current. It can be explained by considering that the voltage across a capacitor is

$$E = \frac{Q}{C}$$

For any given capacitor (C), the voltage depends directly on the charge (Q) which is the imbalance of electrons on the two capacitor plates. The amount of this charge depends on the current flow and the time which this flow exists.

The fact that the voltage is proportional to the integral of the charging current allows the RC

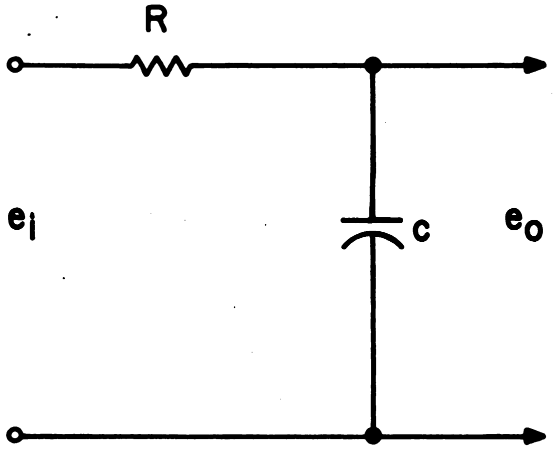

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Figure 3-16.—Simple integrator.

circuit to be used as an integrator. The capacitor voltage is the integrator output. Provision must be made to supply a charging current that is proportional to the input information. The purpose of the resistor is to produce this proportional current from an input signal voltage "e_i." At the instant this voltage is applied, the charging current becomes

$$i = \frac{e_i}{R}$$

Unfortunately this proportionality does not continue to exist. As the capacitor becomes charged, the capacitor voltage opposes the charging current, and the charging current becomes less proportional to the input signal. This results in an error in the output. The ideal output, for a constant input signal is a steadily increasing output. This steady increase is attained only when the signal voltage is first applied and the capacitor has not become appreciably charged.

A remedy to this error in the RC integrator is to use a circuit with a long time constant. Such a circuit delays the charging of the capacitor. The result is a more accurate integration of an input signal. The ideal output would be a perfect triangular wave. Although a long time constant produces more accurate results, it also provides a much lower output for the same input signal. Better integration is possible by the use of a high gain, feedback amplifier.

An amplifier integrator is illustrated in figure 3-17. The circuit arrangement uses a high gain amplifier and is known as the Miller integrator. The amplifier produces an output which is not limited by the input signal as it is in the simple RC integrator. The amplifier also supplies any energy which is required in the output. The function of the input signal is to control the charging current.

The operation can be explained by assuming a constant input as shown in figure 3-17(A). At the start, assume the initial condition is zero, that is,

$$e_i = e_g = e_o = 0.$$

Also assume that the capacitor is discharged. The positive voltage to be integrated, "e_i," is then applied. The capacitor charges with a polarity as shown, since electrons are attracted from the left plate. The charging path is shown in figure 3-17(B).

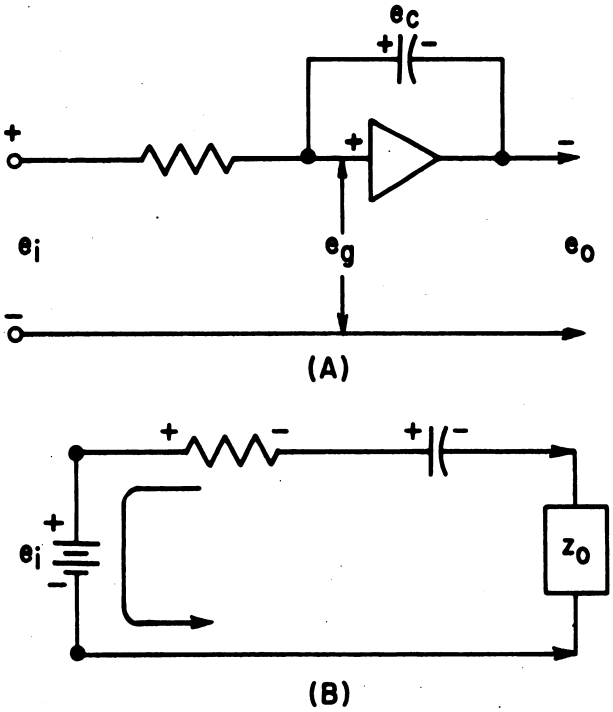

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Figure 3-17.—Amplifier integrator.

A voltage measured at the amplifier input, "e_g," tends to rise in the positive direction since this point is directly coupled to "e_i." However, this rise tends to be opposed by the degenerative feedback voltage from the output. The output will be $-Ae_g(e_o)$. The letter "A" stands for the amplifier gain. The minus sign indicates that the output polarity or phase is opposite to the input. The output changes "A" times faster or steeper than "e_g." The output voltage is negative and aids the charging of the capacitor.

For a certain input voltage, the charging current is limited to a particular value which tends to keep "e_g" practically zero. If the current should exceed this value, "e_g" would decrease a small amount due to the increased voltage drop across R. The e_o would decrease, and the charging current would decrease to the original value. If the initial charging current should decrease, the opposite action would occur. The value of the charging current is therefore stabilized to a specific value proportional to the input voltage. This eliminates the error caused by "e_i" and the charging current not remaining proportional in the fundamental RC integrator.

This constant charging current must be produced by "e_o" despite the fact that the steadily increasing capacitor voltage opposes the charging current. To do this, "e_o" must also steadily increase. This steady increase in "e_o" is exactly the integrator output voltage desired for a constant signal input.

Similar action would be produced for a condition in which the input signal suddenly became negative. Polarities then would be in reverse to those shown in the example given. Remember that simple examples are used for explanation on the assumption that the desired result also will be produced for a more complicated signal input. Removal of "e_i" would produce little effect upon the output which existed at that instant, since the amplifier output would oppose the tendency for the capacitor to discharge.

The limits for "e_o" are determined by the amplifier and not by "e_i" or the range of "e_g." The output range would be designed to produce an increasing output for any probable input amplitude and period of application. The exception to this would be an integrator which was designed to function also as a limiter.

OUTPUT DEVICES

The output of the servocontrol amplifier is fed to an output device. The functions of this device, usually a servomotor, are to supply torque, power, and dynamic characteristics required to position the servo load. Ideally, the power device should require small power from the control amplifier, accelerate rapidly, be of small size and weight, be of lasting endurance, have small time lags, and have an adequate speed range. In aircraft weapons systems, the electric motor is most frequently used as an output device. However, electromagnetic clutches, hydraulic devices, and pneumatic devices are also used.

Electric Motors

In aircraft weapons systems, electric motors are primarily used to drive the servo load. The type of electric motor used within a particular equipment is determined by power factors as type of power available, output power, speed range, inertia, and electrical noise.

ALTERNATING-CURRENT MOTORS.— Alternating-current motors are frequently used in low power servo applications because of their simplicity, reliability, absence of commutator sparking, and rapid response. However, they have a disadvantage of having a narrow speed range characteristic. The theory of operation of ac motors is discussed in Navy Electricity and Electronics Training Series (NEETS) Module 5, NAVEDTRA 172-05-00-79. We briefly discuss the types of motors used with servosystems in this chapter.

The 2-phase induction motor is the most widely used ac servomotor. The stator of the motor consists of two similar windings which are positioned at right angles to each other. The rotor may be wound with short-circuited turns of wire or it may be a squirrel cage rotor. The squirrel cage rotor is the type most frequently encountered. It is made up of heavy conducting bars which are set into armature slots, the bars being shorted by conducting rings at the ends.

Two ac voltages 90° out of phase must be applied to the stator windings in order for the motor to turn. These out-of-phase voltages generate a rotating magnetic field which induces a voltage in the rotor. This induced voltage generates a magnetic field in the rotor that is displaced 90° from the stator magnetic field. The interaction of these two magnetic fields causes the armature to rotate.

As stated previously, the voltage to the two stator windings must be 90° out of phase to cause the rotor to turn. The direction of rotation is determined by the phase relationship of the stator windings which, in turn, is determined by the servo error detector. One phase is connected directly to one of the stator windings while the other phase is used to energize an error detector. The resulting error voltage is either in phase or 180° out of phase with the signal applied to the error detector. This will cause the controlled phase to either lead or lag the uncontrolled phase by 90°.

Most induction motors have low starting torque and high torque at high speed. For servo applications, it is desirable to have high starting torque in order that the system may have a low time lag. This may be accomplished by increasing the armature resistance with the use of materials such as zinc for the conducting bars. This increased torque at low speed results in decreased torque at high speed. However, increased stability of the servosystem is a desirable result of this change.

Split-phase ac motors are similar to the 2-phase induction motor. It differs only in that a phase shifting network is used to shift the phase of the voltage supplied to one of the windings by 90°. This is usually accomplished by connecting a capacitor in series with the uncontrolled winding of the stator. Direction of rotation and reversal is accomplished in the same manner as in the 2-phase motor discussed above.

Other types of motors that may be used with an ac power supply are shaded pole, universal, and repulsion motors. They utilize various methods of obtaining rotation reversal. However, they are seldom found in aircraft weapons systems.

DIRECT-CURRENT MOTORS.—Direct-current motors have an advantage of having higher starting torque, reversing torque, and less weight for equal power than ac motors.

Series motors are characterized by their high starting torque and poor speed regulation with a change in torque. Higher torque can be obtained on reversal of direction with a series motor than any other type. However, it is a unidirectional motor and requires special switching circuits to obtain bidirectional characteristics. This is normally done by switching either the armature or field connections but not both.

A variation of the series motor that has bidirectional characteristics is the split-series motor. The motor has two field windings on its frame, only one of which is used for each direction of rotation. This reduces the number of relay contacts required for reversing by one-half. This double winding also reduces the torque capabilities of the motor as compared to a straight-series motor wound on the same frame.

The most frequently used dc servomotor is the shunt motor. Its direction of motion is controlled by varying the direction of flow of either the armature or field current. The uncontrolled current is usually maintained constant to preserve a linear relationship between the motor output torque and the voltage or current input. The field windings are usually two differentially wound coils to facilitate direction control of the field current by the servocontrol amplifier. The field current is usually controlled with receiving type vacuum tubes. The larger armature currents require thyratrons or generators as current regulators but are not normally found in aircraft weapons systems.

Magnetic Clutches

Any device utilizing an electrical signal that may be used to control the coupling of torque from an input shaft to an output shaft is a magnetic clutch. This coupling may be accomplished by the contact between friction surfaces or by the action of one or more magnetic fields. A magnetic clutch is used only to couple the input torque to the output shaft. Thus, it is capable of controlling large amounts of power and torque for its size and weight. The magnetic clutch may be used with a large flywheel driven at high speed by a small motor. This allows the flywheel to impart very large acceleration to the load when the magnetic clutch is energized.

There are two distinct types of magnetic clutches. Some transmit torque by physical contact of frictional surfaces. Others utilize the action of magnetic flux produced by two sets of coils, or one set of coils and induced eddy currents resulting from rotating the one set of coils near a conducting surface. The eddy current type of clutch offers smoother operation and has no problem of wear, due to friction. Both types have suitable control characteristics and are found in servomechanisms.

HYDRAULIC DEVICES

Hydraulic components used in servomechanisms are frequently found in aircraft weapons systems. Hydraulic power devices, such as motors and associated control valves, have an advantage of a response much faster than the best electric motors and equal to that of a magnetic clutch system. They also require a minimum of maintenance, have very high accuracy, and are well adapted to heavy loads.

The essential components of a hydraulic system are:

1. Source of high pressure oil and sump to receive discharge oil
2. Control valve and means of employing an actuating signal
3. Actuator (motor or cylinder)

The theory of operation of a hydraulic system is discussed in *Fluid Power*, NAVEDTRA 16193 (Series).

The source of high-pressure oil serves as a source of power to operate the actuator. However, this source of power is controlled by the control valve. This valve is actuated by the output from the servocontrol amplifier. This control is normally accomplished by feeding the error signal to a solenoid controlled valve. However, the error signal could be used to drive an electric motor which, in turn, actuates the control valve. The actuator is usually in the form of an axial motor which must be a reversible and variable speed type. Some applications may employ a cylinder where linear motion is required for positioning.

SERVOMECHANISM OSCILLATION

In aircraft weapons systems, servomechanisms are utilized for various functions and must meet certain performance requirements. These requirements not only concern such things as speed of response and accuracy, but the manner in which the system responds in carrying out its command function. All systems contain certain errors, the problem being to keep them within the allowable limits.

As discussed previously, the servomotor must be capable of developing sufficient torque and power to position the load in a minimum of time. The servomotor and its connected load have sufficient inertia to drive the load past the point of command position. This overshooting results in an opposite error voltage, reversing the direction of rotation of the servomotor and the load. The servomotor again attempts to correct the error and again overshoots the point of correspondence with each reversal requiring less correction until the system is in correspondence. The time required for the oscillations to die out determines the transient response of the system and can be greatly reduced by the use of damping.

DAMPING

The function of damping is to reduce the amplitude and duration of the oscillations that may exist in the system. The simplest form of damping is viscous damping. Viscous damping is the application of friction to the output load or shaft that is proportional to the output velocity. The amount of friction applied to the system is critical and will materially affect the results of the system. When just enough friction to prevent overshoot is applied, the system is said to be critically damped. When the friction is greater than that for critical damping, the system is overdamped. However, when damping is slightly less than critical, the system is said to be slightly underdamped, which is usually the desired condition. The application of friction absorbs power from the motor and is dissipated in the form of heat.

A pure viscous damper would absorb an excessive amount of power from the system. However, a system having some of the characteristics of a viscous damper with somewhat less power loss is used in actual practice. The first of this type of damper to be discussed utilizes a dry friction clutch to couple a weighted flywheel to the output drive shaft. A flywheel has the property of inertia, which may be defined as that property of matter by which it will remain at rest, or in uniform motion in the same straight line or direction unless acted upon by some external force.

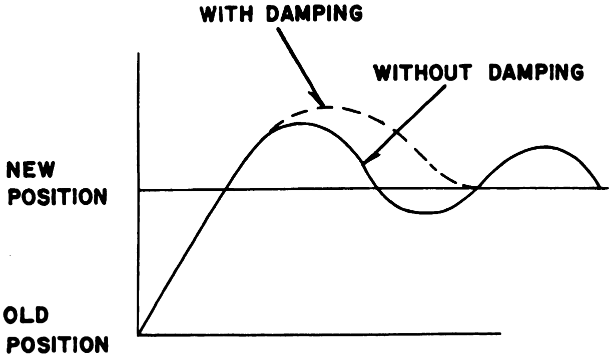
However, since the flywheel is coupled to the output shaft with a friction clutch, any rapid change in velocity of the output member causes the clutch to slip. This slipping effectively disconnects the flywheel instantaneously but allows sufficient power to be coupled to the flywheel to overcome its inertia. As the inertia is gradually overcome, the flywheel gains speed and approaches the velocity of the output member. As the point of correspondence is neared and the error signal is reduced, the inertia of the flywheel gives up power to the system, causing the load to increase its overshoot. When the system attempts to correct for this overshoot, the inertia of the flywheel adds to the output load, reducing the effect of the correcting signal. The effect dampens the oscillations in the system, reducing its transit time.

Another type of damper used is the eddy current damper. This damper utilizes the interaction of induced eddy currents and a permanent magnet field to couple the output shaft to a weighted flywheel.

The effect of damping is shown in figure 3-18. The solid line shows the action of the load without damping. The time required to reach a steady-state condition without damping should be noted. This time is greatly reduced although the initial overshoot is increased.

As shown in figure 3-18, a viscous damper effectively reduces transient oscillations, but it also produces an undesired steady-state error.

How well the load is controlled is a measure of the steady state performance of a servosystem. If the load is moved to an exact given position, then the servosystem is said to have perfect steady state performance. If the load is not moved to the exact position, then the system is not perfect and the difference in error is expressed as the steady state error. Steady state error may be either one or both of the following: velocity lag or position error. Velocity error is the steady state error due to viscous drag during velocity operation. Position error is the difference in position between the load and the position order given to the servosystem.



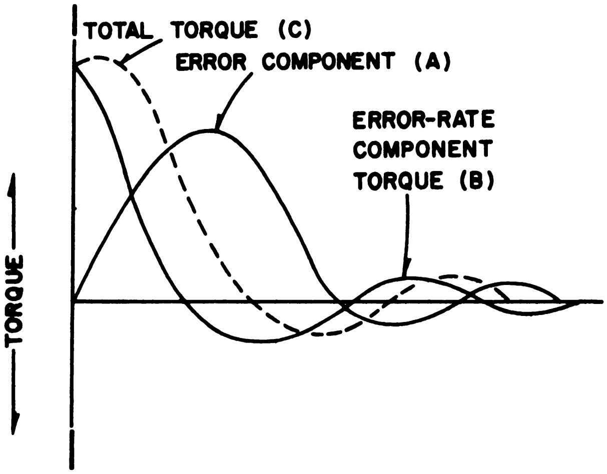
222.300

Figure 3-18.—Effect of friction damper.

Since the friction damper absorbs power from the system, its use is normally limited to small servomechanisms.

To overcome the disadvantages of the viscous dampers and still provide damping, error-rate damping is used. This type of damping consists of introducing a voltage that is proportional to the rate of change of the error signal. This voltage is fed to the servocontrol amplifier and combined with the error signal. Figure 3-19 shows the effect of error-rate damping on the torque output of the servomotor. Curve A shows the torque resulting from the error voltage; curve B shows the torque resulting from the error-rate damper; and curve C depicts the resultant of curves A and B. It should be noted that torque resulting from the damper increases the total torque as long as the error component is increasing. Once the error component starts to decrease, the error-rate damper produces a torque in an opposite direction reducing the transit time of the system.

There are two methods of generating an error-rate voltage normally found in aircraft weapons systems. They are the tachometer and electrical networks. The tachometer error-rate damper utilizes a device which is essentially a generator having an output voltage proportional to its shaft speed. The tachometer is connected to the shaft of the output member giving a voltage proportional to its speed. The output voltage is fed



222.301

Figure 3-19.—Torque variations using error-rate damping.

to a network that modifies this voltage so that it is proportional to a change in input voltage. This voltage is fed back to the servocontrol amplifier and added with the error signal as shown in figure 3-19.

Electrical networks used for error-rate damping consist of a combination of resistors and capacitors used to form an RC differentiating network. For a detailed explanation of RC circuits, refer to Navy Electricity and Electronics Training Series (NEETS) Module 2, NAVEDTRA 172-02-00-79. These networks, sometimes referred to as phase advance or lead networks, vary in design, depending on the type of error signal. However, in practice, networks are normally limited to the dc type (fig. 3-20). This is because of the unstable results that would be caused by a small change in frequency of the power source. An ac system may utilize a dc network by first using a demodulator (detector) prior to the network. However, the output of the network must be modulated for use in the remainder of the ac system. Like the tachometer, the output of the network is fed to the servocontrol amplifier.

INTEGRAL CONTROL

Servomechanisms used in aircraft weapons systems are sometimes required to follow an input function, the magnitude of which changes at a constant rate with time, such as an antenna system tracking a target. Thus, if the input is the angle of a shaft, the velocity of the shaft may be constant for a substantial percentage of time. The servomechanism may be required to respond to this type of input with substantially zero error. The error that characterizes the servo response to a constant velocity input is known as the velocity error.

To correct for velocity error or an inaccuracy due to a steady-state error, an integral control may be used. This control modifies the error voltage in such a manner that the signal fed to the servocontrol amplifier is a function of both the amplitude and time duration of the error signal. This is accomplished by the use of a variable voltage divider whose output would increase with time for a constant input. As in all voltage dividers, the output is only a portion of the input which effectively reduces the amplitude of the error signal. To compensate for the loss of amplitude, additional amplification must be used either in the form of a preamplifier or a higher gain servocontrol amplifier. With the overall gain of the system now increased to give a normal output for transient error signals, small velocity or steady-state error signals of long duration will result in somewhat increased output to the servomotor due to the action of the integral control.

The integral control (fig. 3-21) consists of a combination of resistors and capacitors connected to make an integrator circuit for a dc error signal. The value of the components are such that the capacitor does not have sufficient time to change with fluctuations in error voltage. Only that portion of the transient error signal developed across R1 is impressed on the amplifier. However, with a velocity error or steady-state error of longer duration, the capacitor (C1) charges, increasing the amplitude of the amplifier input.

Networks shown in figure 3-21 are not limited to dc systems as a demodulator may be used prior to the integrator and its output modulated for easier amplification.

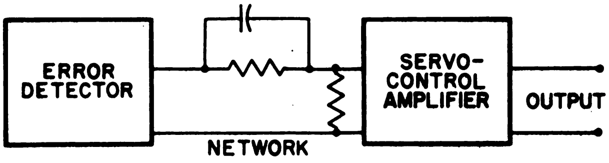


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Figure 3-20.—Error-rate stabilization network.

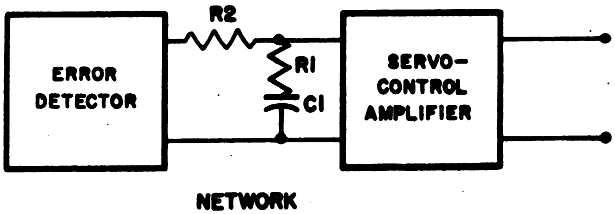

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Figure 3-21.—Integral stabilization network.

GAIN, PHASE, AND BALANCE

The overall system gain has a most important effect on the servomechanism response characteristics and is one of the more easily adjustable parameters in electronics servocontrollers. Increasing the system gain reduces the system velocity errors and those steady-state errors resulting from restraining torques on the servo load or misalignment in the system. An increase in system gain also increases the speed of response to transient inputs. However, excessive gain always decreases the rate at which oscillatory transients disappear, and continued increase in the system gain eventually produces instability.

Servosystems using push-pull amplifiers must be balanced to ensure equal torque in both directions of the servomotor. This adjustment should be checked periodically as a change in value of a component may cause an unbalanced output. Balancing is accomplished by adjusting the system for zero output with no signal applied.

A phase control is included in some servosystems using ac motors. The two windings of the ac servomotor must be energized by ac signals that are 90° apart. A phasing adjustment is normally included in the system to compensate for any phase shift in the amplifier circuit resulting in unstable operation of the system. This adjustment may be located in the control amplifier, or in the case of a split-phase motor, it may be in the uncontrolled winding.

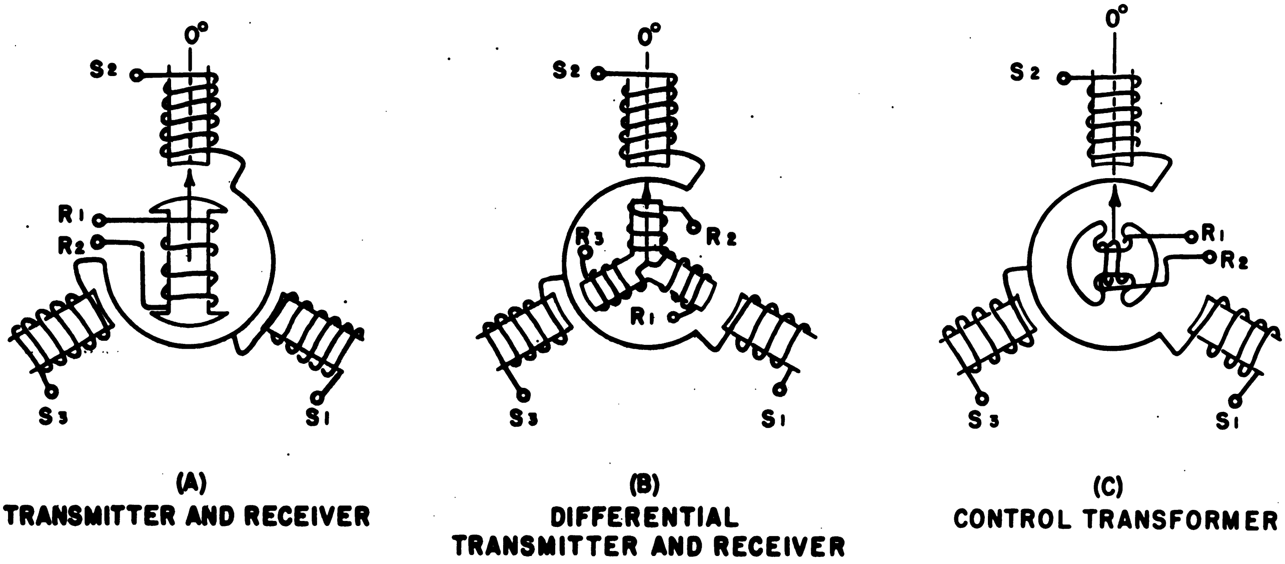
ZEROING SYNCHRO UNITS

In this chapter, we have stressed the importance of accuracy with servomechanisms. In any servomechanism using synchro units, it is also very important that the units be zeroed electrically (fig. 3-22(A)).

For a synchro transmitter or receiver to be in a position of electrical zero, the rotor must be aligned with S2, the voltage between S1 and S3, must be zero, and the phase of the voltage at S2 must be the same as the phase of the voltage at R1.

TRANSMITTERS AND RECEIVERS

The most common methods of zeroing synchro transmitters and receivers are the ac voltmeter method and the electrical lock method. The method used to zero a synchro depends upon how the synchro is used. Where the rotor is free to turn, the electrical lock method can be used.



(A)
TRANSMITTER AND RECEIVER

(B)
DIFFERENTIAL
TRANSMITTER AND RECEIVER

(C)
CONTROL TRANSFORMER

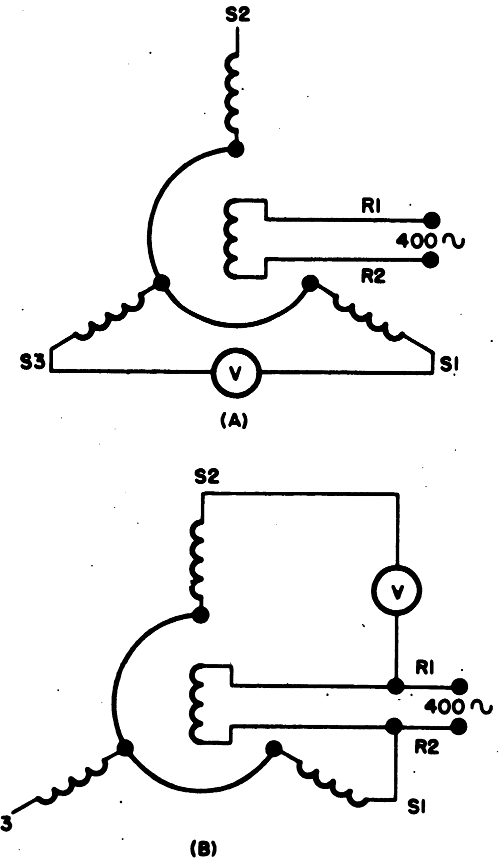
222.304

Figure 3-22.—Synchro electrical zero positions.

This is accomplished by connecting S1 and S3 to R2 using a jumper wire and connecting S2 to R1 (fig. 3-23). When power is applied, the rotor will position itself in the zero position. After the synchro is zeroed, the pointer is adjusted to indicate zero.

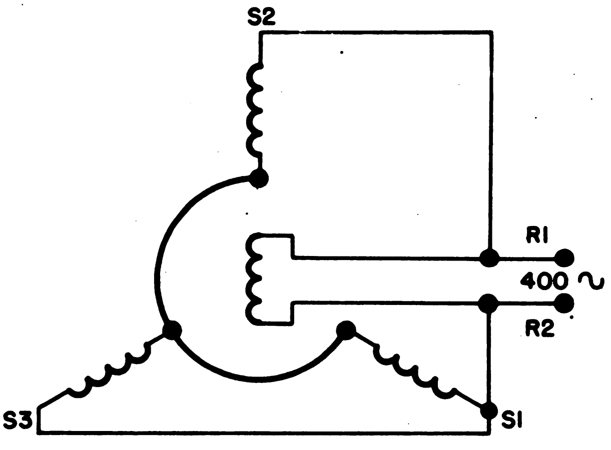
Possibly the great majority of synchros used in aviation weapons systems have their rotors gear driven or mechanically coupled to a driving member. In these cases it is necessary to use the ac voltmeter method, zeroing the synchro by rotating the stator or housing until its electrical zero is reached. Before you zero the synchro, the mechanical unit that positions the synchro must be set to its indexing or ZERO position. This is done by aligning the unit to its index and installing its indexing pins in the holes provided for this purpose. The pins hold the unit to its index and keep it from moving.

The ac voltmeter method is done by connecting the meter and jumper wires as shown in (A) of figure 3-24. Rotate the energized synchro until a zero reading is obtained on the voltmeter. Since rotor positions of 0° and 180° produce this zero reading, it is necessary to determine if the phase of S2 is the same as that of R1. Make the connections as shown in (B) of figure 3-24. If the proper polarity relationship exists, the voltmeter indicates less than the excitation voltage being applied to the rotor. If the indication is greater than the rotor excitation voltage, the rotor (or stator) must be rotated 180° and the previous step must be performed again.



222.306

Figure 3-24.—Ac voltmeter method of electrically zeroing synchro receiver or transmitter.



222.305

Figure 3-23.—Electrical lock method of zeroing a synchro.

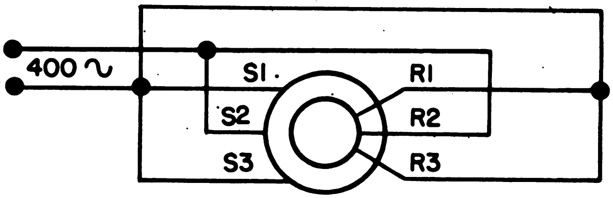
Differential Transmitter

The electrical zero position of a synchro differential transmitter or receiver is when the three windings of the rotor are in correspondence with their respective stator windings and their respective voltages are in phase (fig. 3-22(B)).

Because the differential transmitter synchro is normally used to insert a correction into a synchro system, it is usually driven either directly or through a gear train. Before you zero the differential transmitter synchro, the unit whose position the differential synchro transmits should first be zeroed. After this has been accomplished, connect the differential synchro as shown in figure 3-25(A). Turn the synchro in its mounting until the voltmeter shows a minimum indication. After you complete this step, make the connections shown in figure 3-25(B). Again turn the synchro slightly in its mounting, until a minimum voltage is indicated by the voltmeter.

Differential Receiver

Electrical zero for a differential receiver is illustrated in figure 3-22(B). To zero a differential receiver synchro, make the connections shown in figure 3-26. As soon as the power is applied to the synchro, the rotor assumes a position of electrical zero. The dial can then be set at zero and the unit reconnected to its circuit.



222.308

Figure 3-26.—Electrically zeroing a differential synchro receiver.

Control Transformer

The synchro control transformer is normally zeroed by using the ac voltmeter method. It should be remembered that the electrical zero position of the control transformer is 90° from that of a receiver since the rotor winding must be perpendicular to the stator's resulting magnetic field to have a zero output (fig. 3-22(C)). The coarse adjustment is made by connecting the meter and unit as shown in figure 3-27(A). The rotor is rotated to give a minimum or null reading on the voltmeter. The final adjustment is made by connecting the unit as shown in figure 3-27(B) and displacing the rotor a few degrees in both directions to determine the null or electrical zero position. Once the zero position has been determined, the unit must be locked as discussed previously.

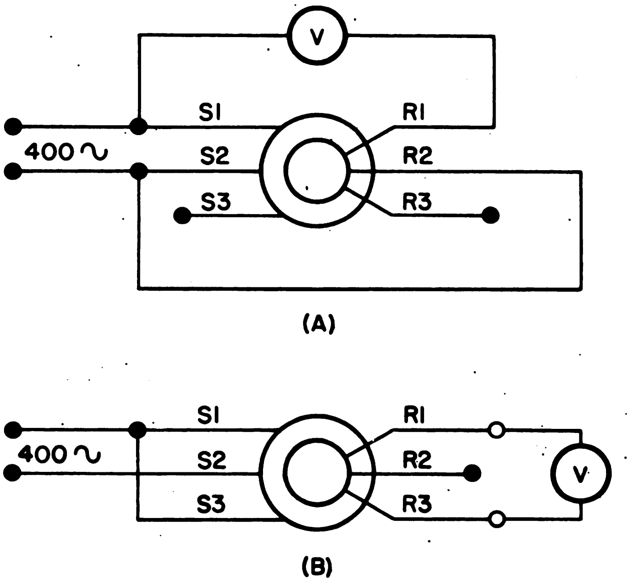


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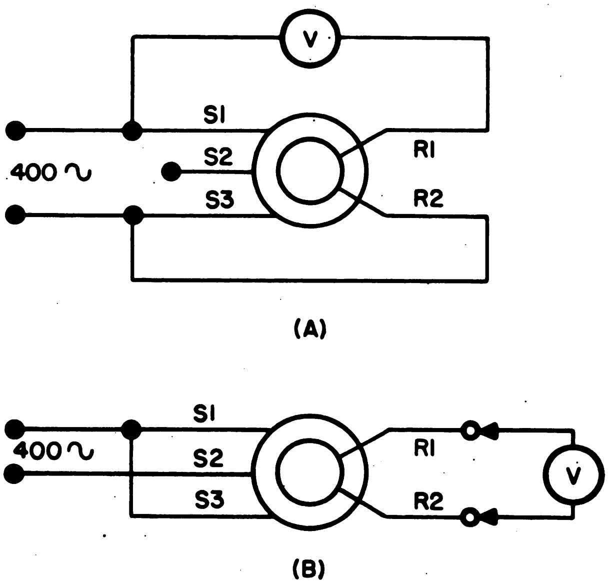
Figure 3-25.—Electrically zeroing a differential transmitter.



222.309

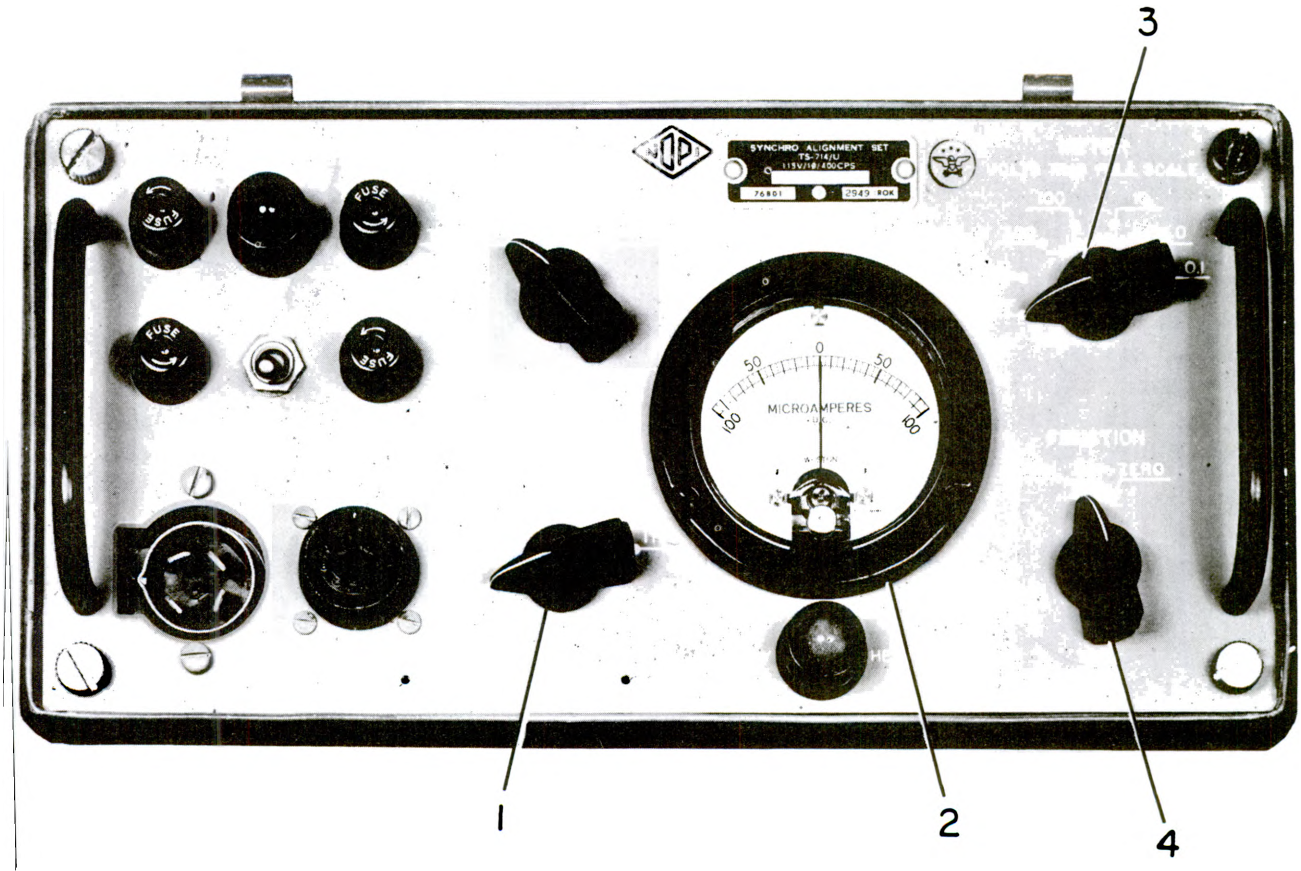
Figure 3-27.—Electrically zeroing a control transformer synchro.

SYNCHRO ALIGNMENT SET TS-714/U

The Synchro Alignment Set TS-714/U (fig. 3-28) is a portable, general purpose test set used to check the alignment of synchros or resolvers. It can be used to align any 400 Hz synchro or resolver. In addition to its higher sensitivity, the test set has an additional advantage over the methods previously discussed because the test set can also supply excitation voltage for the synchro or resolver being aligned.

The test set basically consists of a bandpass amplifier and power supply, a synchro or resolver excitation supply with outputs from 3 to 115 volts rms (1, fig. 3-28) and switching circuits. The output voltages from the synchros or resolvers are applied to the amplifier, the output of which is fed to a phase sensitive detector circuit. The detector's output is metered by the microammeter (2). A meter switch (3) selects the meter sensitivity from 300 volts full scale to 0.1 volt full scale, plus a calibrate and off position.

The meter has a ZERO center scale and indicates 0 when the synchro or resolver is adjusted to either of its two nulls. The synchro or resolver is adjusted to a null position with the function switch (4) in the ZERO position. When



1. EXCITATION VOLTS RMS switch.
2. MICROAMMETER.
3. METER switch.
4. FUNCTION switch.

222.15

Figure 3-28.—Synchro Alignment Set TS-714/U front panel.

the null is reached, the function switch is switched to the POL position and note is taken of the meter reading. Then the function switch is returned to the ZERO position and the synchro is rotated 180° to its opposite null. When the opposite null is reached, the function switch is again switched to the POL position and a note made of the reading. The correct null will be the one indicating the lowest reading with the function switch in the POL position. When the synchro is adjusted to this null, it is electrically zeroed with the correct polarity.

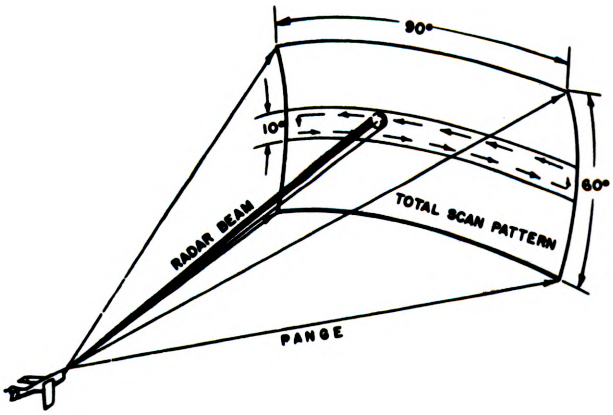
For detailed instructions on the use of the TS-714/U, consult *Operation and Service Instruction Manual,* NA 11-70-FAG-510.

ANTENNA POSITIONING SERVOSYSTEM

In this section, the application of a servomechanism to position a radar antenna and supply target information to the weapons system is discussed. However, before discussing the servosystem, consider the scan pattern of a typical aviation fire control radar.

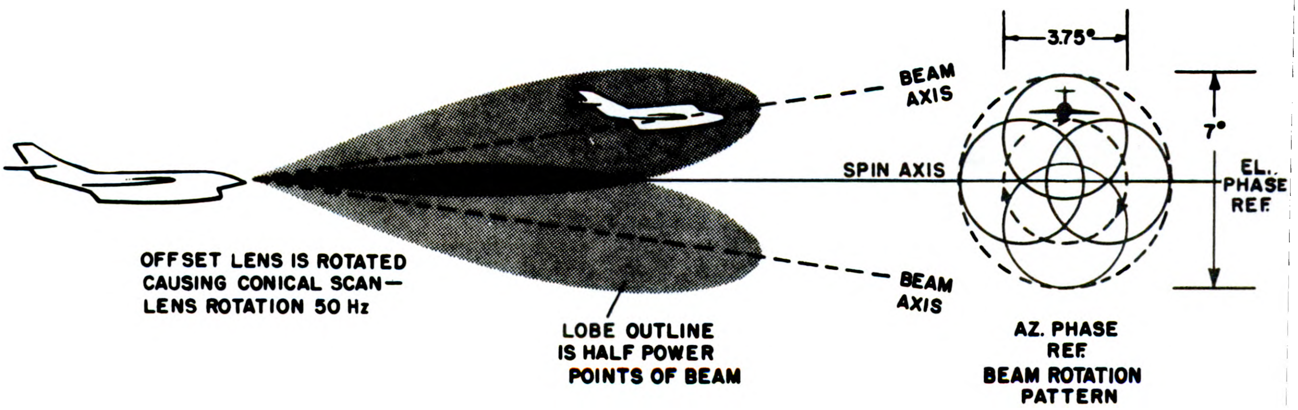
The antenna radiator and reflector form a conical pattern of circular symmetry with beam dimensions as shown in figure 3-29. The antenna assembly contains a spinner motor that rotates the beam about the antenna axis to produce a 7° conical scan. While the radar is in the search mode of operation, the rotating cone scans both horizontally and vertically, covering an area of 10° vertically by 90° horizontally (fig. 3-30). The search pattern may be positioned vertically from a positive 30° to a negative 30° by the antenna positioning level.

The operator normally observes the targets, identifies each as friend or foe, and determines which target, if any, to pursue. Since the antenna utilizes its 7° conical pattern only during track operation, some means must be provided for positioning the antenna on the selected target to



222.17

Figure 3-30.—Typical antenna scan pattern.


3.75°
BEAM AXIS
7°
SPIN AXIS
EL. PHASE REF
BEAM AXIS
OFFSET LENS IS ROTATED CAUSING CONICAL SCAN— LENS ROTATION 50 Hz
LOBE OUTLINE IS HALF POWER POINTS OF BEAM
AZ. PHASE REF
BEAM ROTATION PATTERN

222.16

Figure 3-29.—Antenna beam with conical scan.

begin the track operation. This is accomplished by bracketing the selected target with strobe lines. When the target has been selected and bracketed, a lock-on switch is depressed, positioning the antenna on the predetermined target, and placing the equipment in the automatic track mode of operation. The antenna is now positioned by the radar receiver output, keeping the target centered in the 7° beam.

A block diagram of a typical fire control antenna servosystem is shown in figure 3-31. It should be noted that the azimuth channel of the antenna control system has been omitted, as its operation is similar to the elevation channel. Since the antenna servosystem utilizes different components during search and track operation, the system used in each mode of operation is discussed separately.

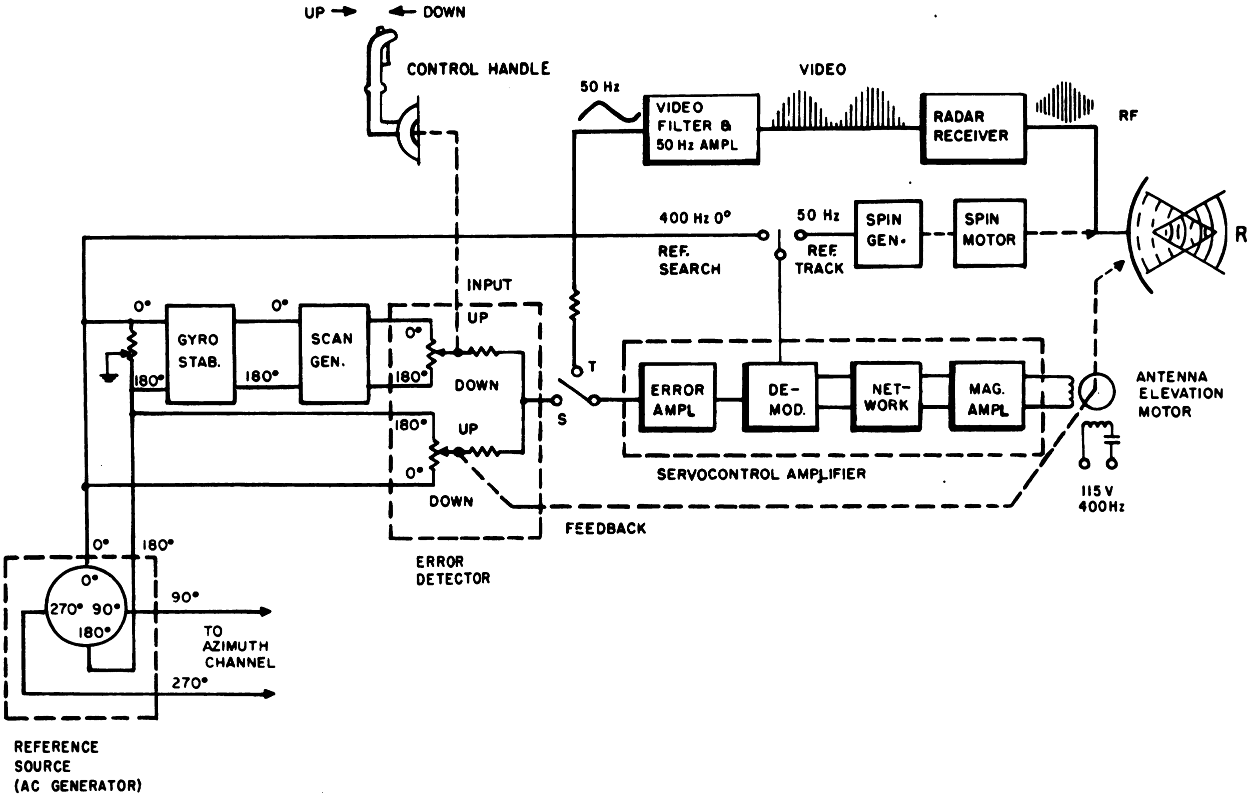
SEARCH OPERATION

The main components of the antenna servosystem used during search operation are as follows:

1. Error detector and its ac voltage source
2. Servoamplifier
3. Servomotor
4. Data transmission system

The ac generator supplies voltage to the input and feedback potentiometers of the balanced potentiometer error detector. However, the voltage fed to the input potentiometer is fed through a gyro space stabilizer and scan generator.

The function of the gyro space stabilizer is to cause the antenna to scan a selected area 90° horizontally and 10° vertically, regardless of any roll or pitch of the aircraft. As in all fire control



222.18

Figure 3-31.—Antenna elevation servosystem functional block diagram.

equipment of this type, the amount of correction that can be made by the gyro space stabilizer is limited by the limit of the radar scanner. The output of the gyro space stabilizer is an ac voltage, the amplitude of which is a function of the roll and pitch of the aircraft. The principles of operation of gyros are discussed later in this manual.

The function of the vertical scan generator is to automatically position the antenna in the vertical geometric plane. Refer to figure 3-30. Note that the antenna scans horizontally and vertically. The scan generator provides the necessary voltage change to cause the antenna to change its angle of elevation by 3° when the antenna reaches its azimuth limits.

The error detector has three inputs that are summed and compared against the antenna's position. The gyro space stabilizer and scan generator constitute two inputs by controlling the amplitude of the voltage supplied to the input potentiometer. The third input is the control handle which positions the wiper contact of the input potentiometer. The output of the error detector is an ac voltage whose amplitude and phase is determined by the voltages on the wipers of the potentiometers.

The error signal is fed to the servoamplifier where it is amplified and compared with the phase of the reference voltage. The phase of the output voltage causes the servomotor to rotate in a direction reducing the error voltage.

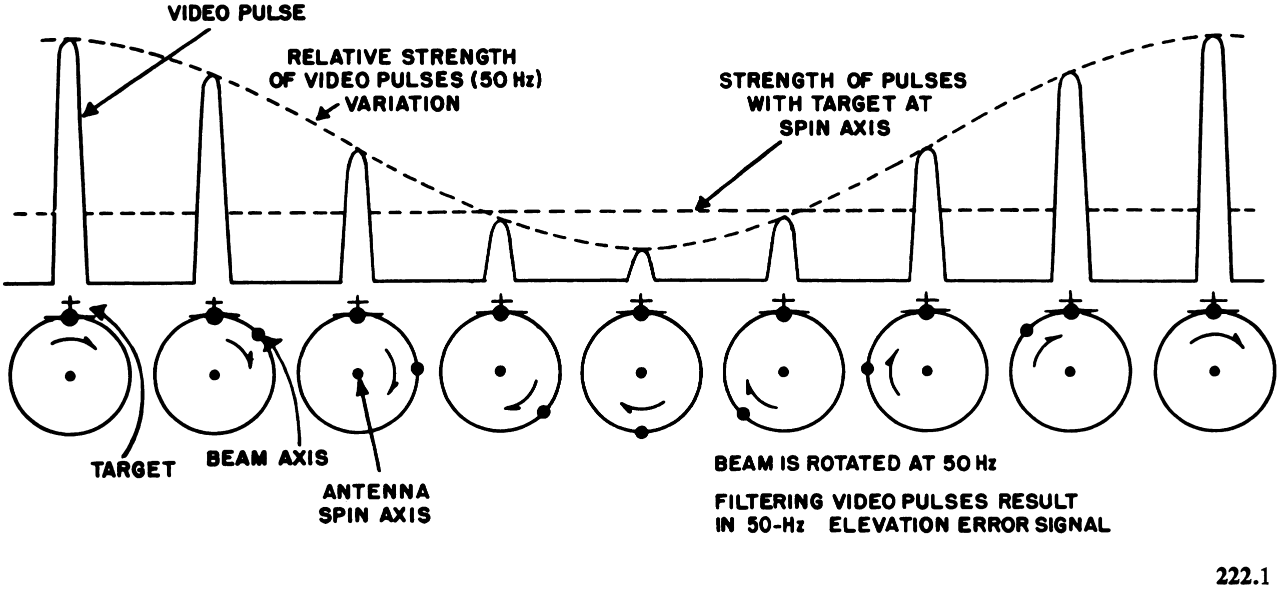
The data transmission system is the mechanical linkage necessary to drive the wiper of the feedback potentiometer, indicating the actual position of the antenna in the vertical plane at all times.

TRACK OPERATION

The main components of the servosystem employed during track operation are:

1. Radar receiver and 50-Hz amplifier
2. Servoamplifier
3. Servomotor
4. 50-Hz spin generator

The radar receiver functions as the error detector, supplying a 50-Hz error voltage. Before discussing the other components of the system, first determine how the receiver provides the error signal. As stated previously, the antenna axis is centered approximately on a target prior to going into track operation. The antenna is rotating at


VIDEO PULSE
RELATIVE STRENGTH OF VIDEO PULSES (50 Hz) VARIATION
STRENGTH OF PULSES WITH TARGET AT SPIN AXIS
TARGET
BEAM AXIS
ANTENNA SPIN AXIS
BEAM IS ROTATED AT 50 Hz
FILTERING VIDEO PULSES RESULT IN 50-Hz ELEVATION ERROR SIGNAL

222.1

Figure 3-32.—Derivation of elevation error signal.

50 revolutions per second while the radar transmitter is transmitting a pulse of energy 450 times per second. When the antenna axis is pointing directly at the target, the target return and receiver video output remain at a constant level. However, if the target were above the antenna axis as shown in figure 3-32, the amplitude of the video would vary as the antenna rotated about its axis. It should be noted that the video amplitude is maximum when the beam axis is at its highest elevation and minimum when the beam axis is at its lowest elevation. The video output from the receiver is filtered, leaving only the 50-Hz envelope to be employed as an error voltage.

The function of the servoamplifier is to amplify the 50-Hz error voltage and compare its phase with the phase of the 50-Hz reference voltage originating in the 50-Hz spin generator. The phase of the output voltage to the servomotor causes the motor to rotate in the direction which reduces the amplitude of the error signal.

THEORY OF SEARCH OPERATION

The schematic diagram of the antenna servosystem described above is shown in figures 3-33(A) and (B). As in the case of the block

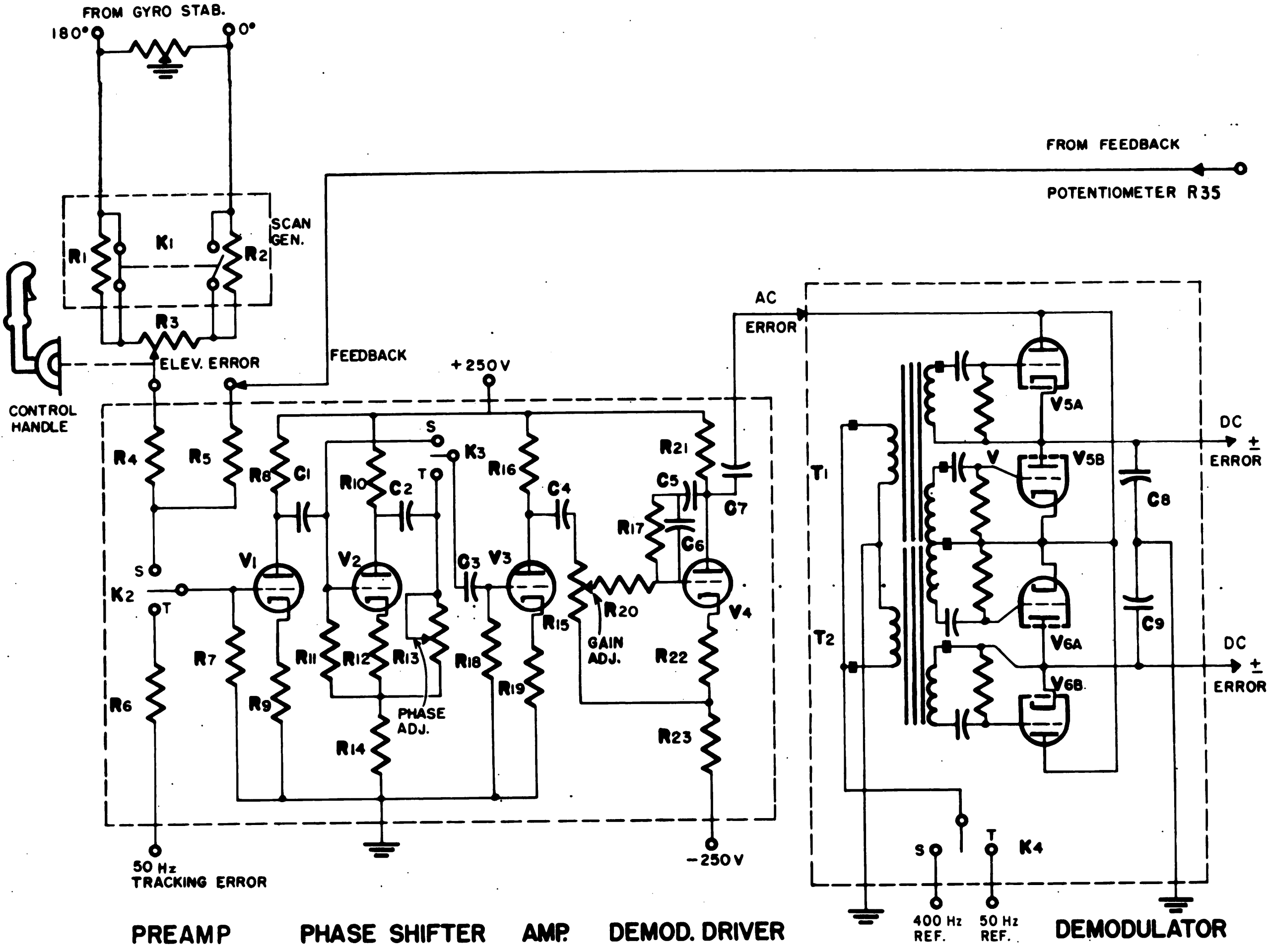


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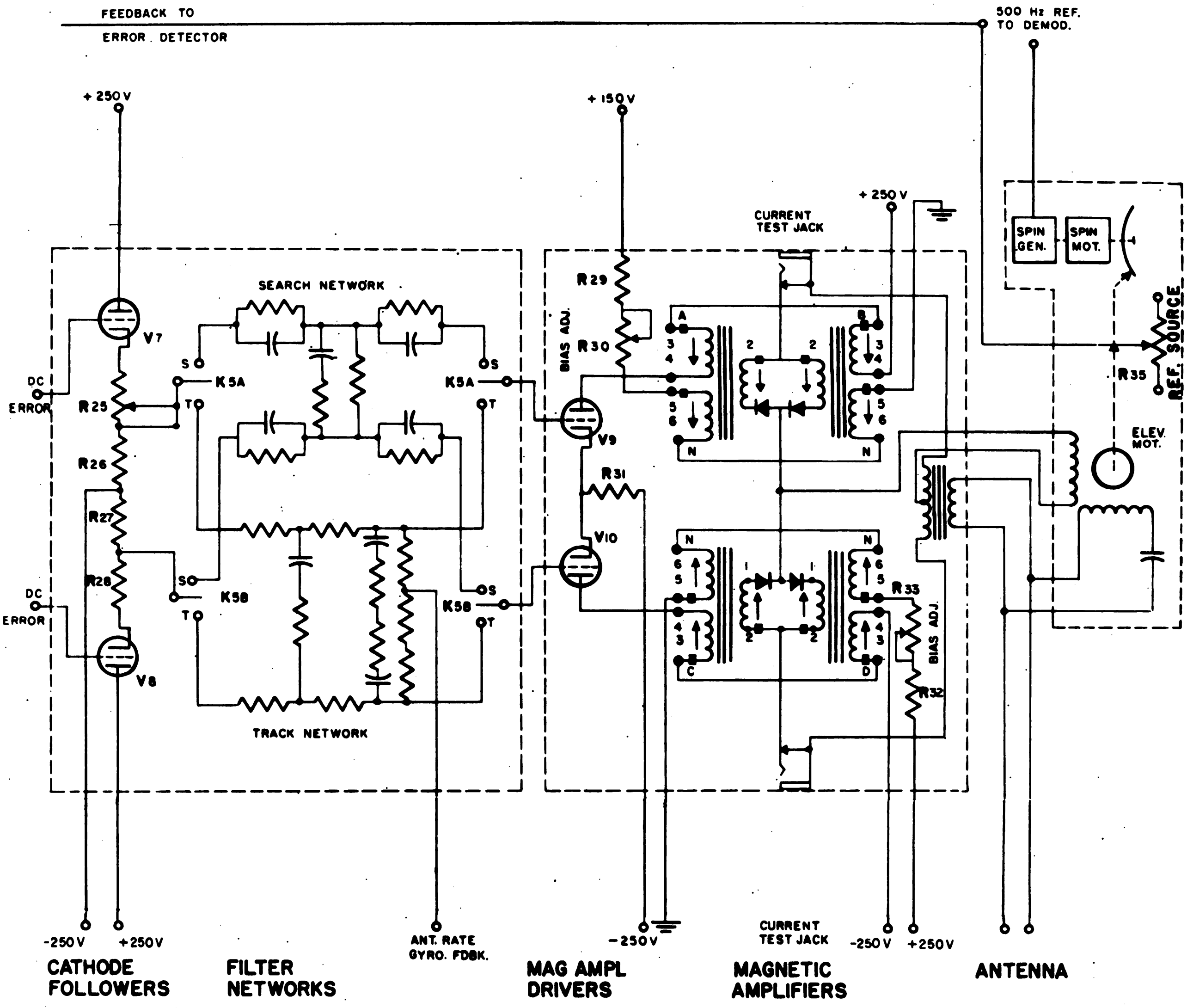
Figure 3-33.—(A) Servosystem schematic diagram.

diagram, the system's search mode of operation is discussed first.

Scan Generator

The elevation scan generator is utilized during automatic search only. It consists of two resistors and one double-pole relay. Since only one resistor is in the circuit at a time, they serve alternately to unbalance the voltage applied to the error-detector potentiometer R3. The input to the scan generator is an ac voltage with its center point grounded by a resistor network. With both R1 and R2 shorted, the center of R3 would also be at ground potential. Inserting R1 in the circuit would cause the center of R3 to be at some potential just as though the wiper of R3 has been moved to the right. Shorting R1 and inserting R2 should have the same effect as moving the wiper of R3 to the left.



222.21

Figure 3-33.—(B) Servosystem schematic diagram.

The relay is actuated by a cam attached to the azimuth limit mechanism; the cam operates when the antenna reaches either azimuth limit.

Error Detector

The balanced potentiometer error detector consists of potentiometers R3 and R35. Potentiometer R35 is supplied with a 400-Hz reference voltage of approximately 32 volts amplitude while the reference voltage applied to R3 is modified in the manner that we have described. This voltage source is center tapped and grounded, thus reflecting an apparent ground at approximately the center of each potentiometer. A control handle displacement causing a change in the wiper contact of R3 results in an unbalanced voltage condition with an error signal being fed to the search contact of relay K2. With the equipment on search, the error signal is applied to the servoamplifier.

Servoamplifier

The servoamplifier consists of the following stages:

1. Preamplifier
2. Phase shifter amplifier
3. Amplifier
4. Demodulator driver
5. Demodulator
6. Cathode followers
7. Search/track network
8. Magnetic amplifier drivers
9. Magnetic amplifier

Preamplifier V1 receives the error voltage from relay K2 and amplifies it. The preamplifier output is coupled through C1 to the grid of V2 and to the relay K3.

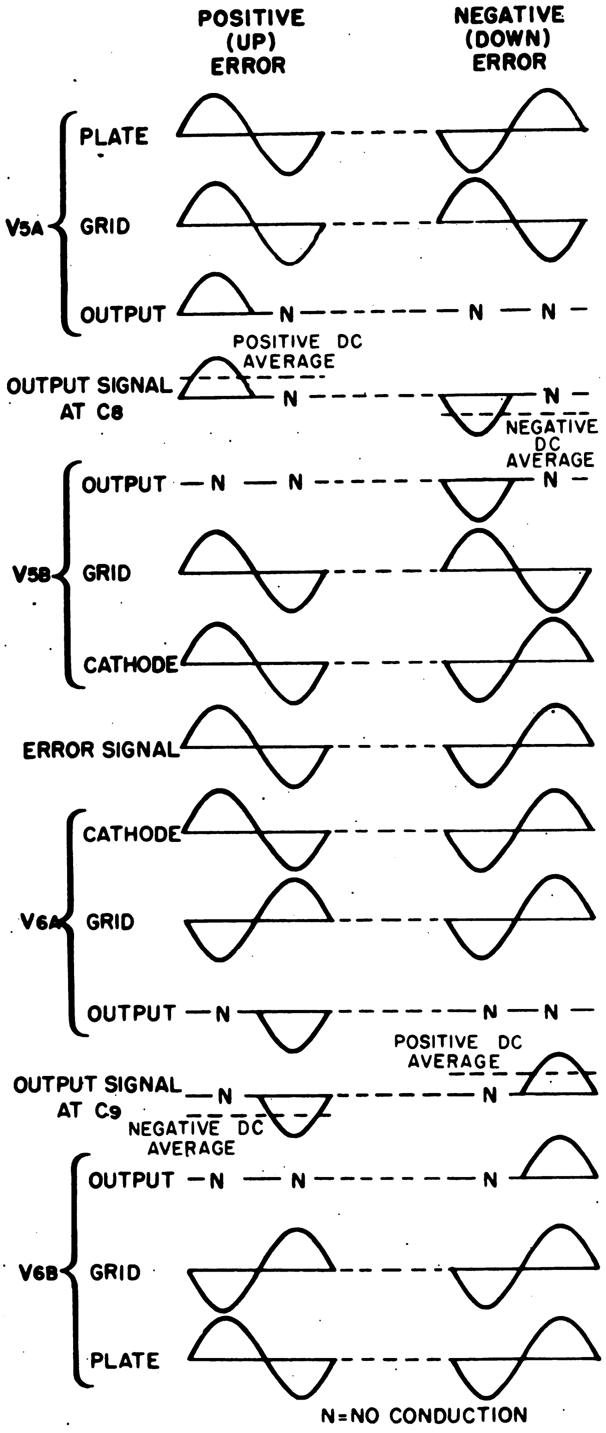
Phase shifter amplifier V2 is bypassed during search operation and is discussed under track operation.

Amplifier V3 provides an additional stage of amplification of the error signal. Its output is coupled through C4 to the gain control R15. The gain control determines the amplitude of the error signal fed to the demodulator driver. Thus, the gain of the antenna servosystem is controlled by R15.

The demodulator driver provides the final amplification of the error signal prior to demodulation. As pointed out above, the amplitude of the signal applied to the grid can be controlled by the gain potentiometer (R15). The gain of the stage is stabilized by degenerative feedback. The feedback is accomplished by two means, an unbypassed cathode resistor R22 and a plate-to-grid feedback loop consisting of C5, C6, and R17. In addition to gain stabilization, the plate-to-grid loop provides the characteristic of an error-rate damper.

The full-wave demodulator employs the use of two dual triodes, V5 and V6. Its operation is somewhat similar to that of a triode demodulator. The input error signal from the demodulator driver is applied to either the plate or cathode of the demodulator triodes. The reference voltage, which is 400 Hz during search operation, is supplied to the grids through either T1 or T2 with the primary-secondary phase relationship as shown in figure 3-33(A). (NOTE: The small black rectangles on the input and output leads of the transformers in figure 3-33(A) are polarity marks. Instantaneous voltage polarity at the transformer primary polarity mark corresponds to the same polarity at the secondary polarity mark.)

Figure 3-34 shows a synchrogram of the voltages existing in the demodulator. It should be noted that when the error signal and reference voltage are in phase, V5A conducts on the first half-cycle and V6A conducts on the second half-cycle. Since V5B is cut off during the time V5A is conducting, V5A draws electrons from the top plate of C8, charging it positive. During the second half-cycle, electrons flowing through V6A are deposited on the lower plate of C9, giving



222.22

Figure 3-34.—Synchrogram of demodulator waveforms.

it a negative charge. This action results in a push-pull output being supplied to the cathode followers.

When the error signal is 180° out of phase with the reference voltage, V5B and V6B conduct on alternate half-cycles, charging C8 and C9 to the opposite polarity.

The cathode followers, V7 and V8, isolate the dc output of the demodulator from the low impedance of the search network. (See fig. 3-33(B).) Potentiometer R25 is provided to balance the outputs of V7 and V8 when no error signal is present.

The search/track network consists of two RC band-pass filter networks which have fairly long time constants. The search filter networks pass a 5-Hz signal while sharply attentuating lower frequencies. This action counteracts the high gain of the magnetic amplifiers giving a flatter overall response for the servosystem.

The magnetic amplifier drivers are dc amplifiers that control the current through the magnetic amplifier's control windings. The dc error signal is applied directly to the control grids of the drivers. The amplified dc error signal is applied to the control windings controlling the output of the magnetic amplifier.

The magnetic amplifier provides the final stage of amplification of the error signal prior to the servomotor or output member. The amplifier consists of four amplifier sections: A, B, C, and D. Each amplifier section has three windings on its core-control, bias, and load. Referring to figure 3-33(B), note that the control and bias windings of sections A and B are connected in series. The bias level is determined by the setting of potentiometer R30, and the control current is determined by the output of magnetic amplifier driver V9.

The C and D sections are connected in a similar manner with the bias level determined by potentiometer R33 and control winding current determined by the output of magnetic amplifier driver V10. It should also be noted that the load winding of each section has a rectifier connected in series with it, allowing current to flow only in one direction. The polarity of the magnetic field resulting from current in each winding is indicated on the schematic by the direction of the arrows.

A synchrogram of waveforms illustrating the operation of the magnetic amplifier is shown in figure 3-35. With a zero error signal applied to the grids of V9 and V10, conduction in all sections of the amplifier is equal. Waveforms showing the amount and time of conduction of each amplifier section under zero error signal conditions are shown in column A of figure 3-35. It should be noted that waveforms (4) and (6) are equal in amplitude in column A but 180° out of phase, resulting in zero output to the servomotor.

Column B of figure 3-35 illustrates the operation of the amplifiers with a positive error (an error signal that would cause the antenna elevation angle to be increased) applied to the magnetic amplifier drivers. The positive voltage applied to the grid of V9 increases the degree of core saturation, reducing the impedance of amplifier sections A and B. The negative voltage applied to the grid of V10 decreases the degree of core saturation, increasing the impedance of amplifier sections C and D. Since the output of a magnetic amplifier varies inversely with its impedance, the output of sections A and B is increased in amplitude while the output of sections C and D is reduced in amplitude. Waveform (5) shows the algebraic sum of the two waveforms which is fed to the servomotor.

Column C of figure 3-35 illustrates the operation of the amplifiers with a negative error signal applied. It should be noted that the output amplitudes have been reversed, causing the signal applied to the servomotor to be 180° out of phase with that in column B.

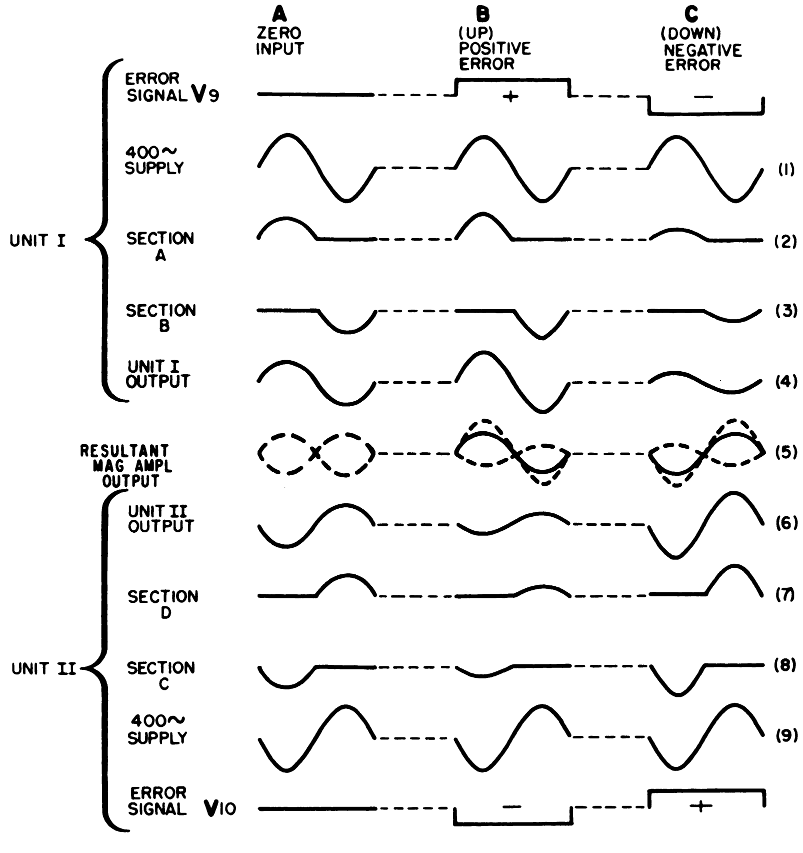


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Figure 3-35.—Magnetic amplifier synchrogram.

Servomotor

The servomotor is a split phase ac induction motor whose field windings are excited by voltages that are 90 electrical degrees out of phase. The output of the servoamplifier determines whether the controlled winding is leading or lagging the uncontrolled winding. This phase relationship also determines the direction of rotation of the servomotor.

THEORY OF TRACK OPERATION

The purpose of the antenna servosystem during track operation is to position the antenna based on the video output of the radar system. Again referring to figure 3-33(A) and (B), note that relay K2 disconnects the error detector and control handle from the servo loop. The 50-Hz envelope of the video output constitutes the error signal and is fed to the servoamplifier.

Servoamplifier

The 50-Hz error signal is amplified by the preamplifier and fed to the phase shifter. The phase shifter amplifies the error signal and also provides an adjustment, R13, to compensate for any phase shift of the error signal through the servoamplifier. (See fig. 3-33.) The output of the plate is coupled through C2 to R13 with the other end of R13 connected to the junction of R11 and R12. The plate and cathode voltages are 180° out of phase and regenerative current flows in R12, resulting in regenerative feedback. The shifting of the error signal's phase is accomplished by varying the resistive-reactive ratio of the plate-to-cathode feedback loop. This varies the phase of the regenerative feedback, controlling the phase of the output error signal.

The operation of the amplifier and demodulator driver stages is identical under both modes of operation. However, the demodulator must now employ a 50-Hz reference voltage. Relay K4 is energized by the track/search switch, disconnecting the 400-Hz reference and connecting the 50-Hz reference supplied by the 50-Hz spin generator.

The outputs of the demodulator are fed through the cathode followers to the track section of the search/track networks. The track section is composed of two identical RC bandpass filters, which pass 2-Hz signals and attenuate all other signals. A signal from the elevation rate gyro is also used to control the error signal amplitude during track operation.

Since the magnetic amplifier drivers and magnetic amplifier utilize dc error signals only, their operation is unchanged when switched to track operation.

Spin Generator

The 50-Hz spin generator is a permanent magnet ac generator that is driven by the spin motor. Its only function is to furnish a reference voltage for the demodulator during track operation.

MAINTENANCE AND ADJUSTMENTS

The maintenance of the antenna servosystem is normally covered during phased inspections of the entire system. However, it is the purpose of this section of the chapter to discuss maintenance pertinent to a typical antenna servosystem.

Lubrication

The lubrication of the antenna system should follow the procedure set forth in the maintenance instruction manual for the equipment. The lubricants and the time interval between lubrications should also be in accordance with standards established by the maintenance instructions. Instructions are normally issued by the squadron, supplying supplemental maintenance information and establishing schedules to be followed by maintenance personnel.

Alignment

The procedure for alignment of the antenna servosystem is also found in the maintenance instruction manual for each equipment. However, the alignment procedures applicable to the basic antenna servosystem are discussed here.

The first adjustment to be made is the balance control, R25 (fig. 3-33). Its purpose is to ensure that there is no output from the servoamplifie when no error signal is applied. Connect a d voltmeter between the grid of V9 and the grid o

V10. Place a jumper between the grid of V7 and the grid of V8. This shorts out any error signal and allows any imbalance of the cathode followers to be determined. Adjust R25 until there is a zero voltage reading on the voltmeter. Remove the voltmeter from the circuit, but do not disconnect the jumper as it is required for the next adjustment.

The bias adjustments in the magnetic amplifiers are made by connecting a milliammeter in the load winding of each amplifier and adjusting the bias controls, R30 and R33, to the current specified by the maintenance instruction manual. A current jack is normally incorporated in the equipment to facilitate the use of standard milliammeters. Remove the jumper from the grids of the cathode followers and disconnect the meter.

The gain adjustment is made by inserting a voltage of a specific amplitude and frequency at the input of the preamplifier and measuring the output of the demodulator driver V4, which is the last ac amplifier stage. The maintenance instruction manual will normally specify the amplitude and frequency of the input signal as well as that of the output stage.

The phase adjustment is made when the equipment is in track operation and locked on a strong target. Disable the antenna azimuth channel by removing the demodulator tubes or at some other location specified by the maintenance instruction manual. With the equipment operating as specified above, manually rotate the antenna in azimuth. Any change in the elevation of the antenna indicates an undesirable phase shift in the amplifier. The phase adjustment must be varied until any movement of the antenna in azimuth causes no change in its elevation.

Adjustment potentiometers normally have locknuts to prevent vibration from affecting their setting. The locknut must be loosened prior to adjusting and care taken when tightening in order not to disturb its setting. The locknut is normally sealed with glyptol to prevent the locknut being loosened due to vibration.

HYDRAULIC SERVOSYSTEM

Another type of antenna servosystem that is in use is a hydraulically driven antenna. This system has the advantages of low response time to a command signal, low weight-to-power ratio, and a high degree of accuracy. Figure 3-36 shows a simplified block diagram of such a system. Only the azimuth channel is shown, as the elevation channel functions similarly.

The antenna drive system converts the electrical energy from the magnetic amplifier into hydraulic pressure which is used to drive the antenna. Antenna position information is mechanically coupled to the induction followup potentiometer which sends a feedback voltage to the magnetic amplifier, nulling out the command signal.

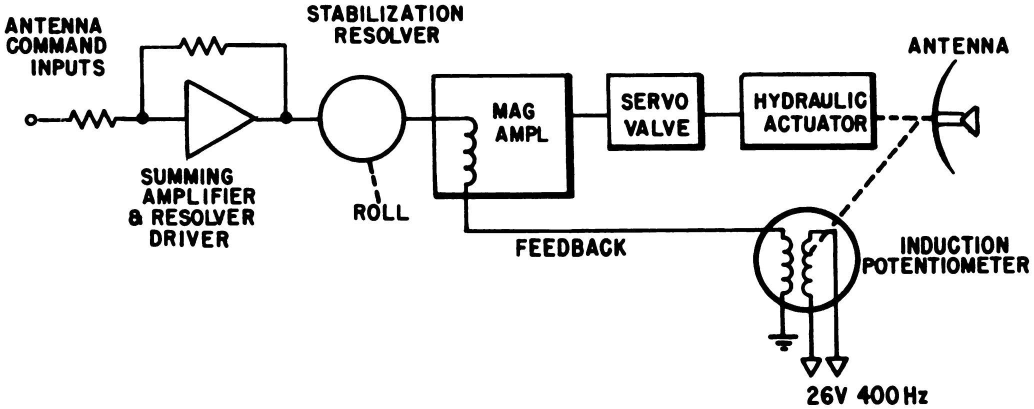

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Figure 3-36.—Antenna positioning circuit.

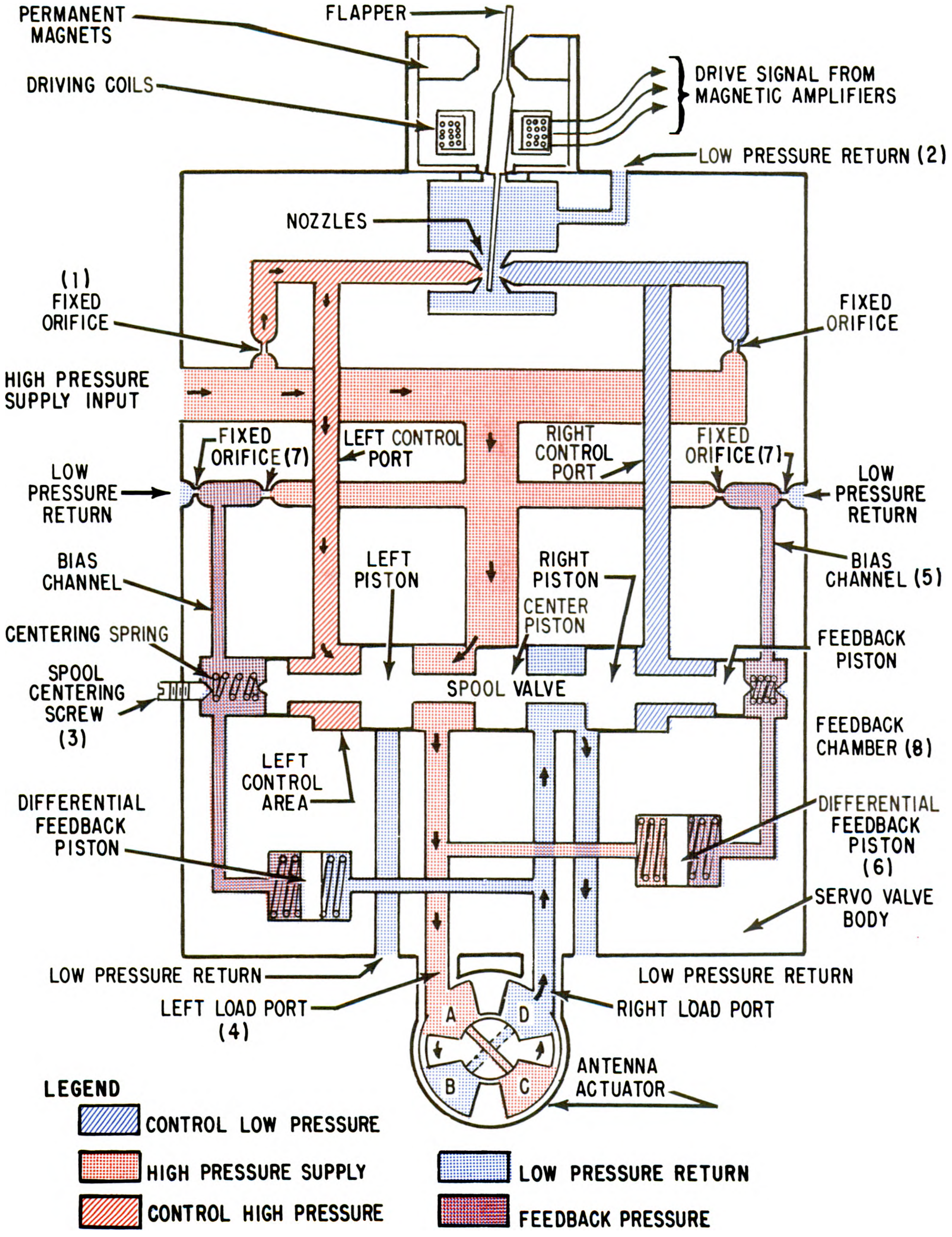

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Figure 3-37.—Servo valve and actuator.

Figure 3-37 shows a diagram of a servo valve and actuator which is used to actuate an antenna. Two such devices are required, one for azimuth and one for elevation.

Drive signals from the magnetic amplifier, acting on the driving coils, produce forces on the flapper at the permanent magnet airgap. Hydraulic fluid, under pressure from the aircraft's hydraulic system, enters the servo valve through fixed orifices (1). After passing through the fixed orifices, the fluid continues through the variable area exit nozzles and then to the low-pressure return (2).

Normally, the flapper is positioned so that an equal amount of hydraulic fluid flows through each nozzle; thus the pressures in the right and left control ports are equal and the forces on the spool valve are balanced. The spool valve is positioned so that with zero signal conditions, the pistons on the spool valve close off the hydraulic supply and return lines to the antenna actuator. The spool centering screw (3) can be used to adjust the position of the spool valve by balancing the forces developed by the spool valve centering springs.

The flapper moves when a signal passes through the driving coils; the direction and amount of movement depend upon the polarity and magnitude of the drive signal. Movement of the flapper valve to the left increases the pressure in the left control port because the flapper restricts the amount of flow through the left nozzle. Also, flapper movement to the left allows more fluid to flow through the right nozzle, thus reducing pressure in the right control port. The resulting pressure imbalance results in movement of the spool to the right until the counterforce developed by the compression of the spool valve centering spring equals the force developed by the pressure difference across the spool valve. As the spool valve moves to the right, the center piston allows an amount of hydraulic fluid proportional to the drive signal from the magnetic amplifier to flow from the high-pressure supply through the left load port (4) into the actuator.

Hydraulic fluid applied to the left load port produces an increase in pressure in chamber A and the pressure increase is transmitted through a hole in the rotor to chamber C. At the same time, chambers B and D are connected to the low pressure return line by the right piston on the spool valve. The pressure difference between the chambers produces a counterclockwise torque on the moving vanes of the rotor. The rotor is connected directly to the antenna gimbal, so that motion of the rotor moves the antenna.

You should be aware of the tendency of servosystems to oscillate. Various types of mechanical and electronic devices (dampers) are used to minimize these tendencies. In hydraulic servosystems oscillation can be damped by the use of hydraulic pressure feedback.

The feedback system is an integral part of the antenna servo valve and consists of a bias channel (5), a feedback channel from each of the antenna actuator drive channels, a differential feedback piston (6), and a feedback piston which is part of the spool valve. Each servo valve has two derivative feedback paths, which together form a push-pull system. Hydraulic fluid from the high-pressure supply flows to the return line through two fixed orifices (7), which are designed so that the bias pressure in the chamber between the orifices is approximately equal to one-half the supply pressure. The bias pressure is applied to one side of the differential feedback piston (6), which moves until the restoring force developed by the appropriate centering spring in the piston chamber equals the force developed by the bias pressure.

The other side of the differential feedback piston is connected through the feedback channel to the load port of the opposite channel. The cross-coupling makes the feedback 180° out of phase with the driving signal, providing negative feedback. The steady-state pressures in the two feedback chambers (8) are equal, because in the absence of differential feedback piston motion, the feedback chamber pressures are determined by the supply and return pressures at the fixed orifices. Any change in the input drive signal changes the pressure in the appropriate load port. When coupled through the feedback channels, the pressure change causes the differential feedback pistons to move so that the pressures in the feedback channels and the bias channels tend to be equalized. However, the change in bias pressure (caused by the movement of the differential feedback piston) bleeds off into the low-pressure return line at a rate determined by the size of the fixed orifices (7), returning the forces on the feedback pistons to their balanced condition.

While the differential feedback piston is in motion, the pressure it develops within its chamber opposes the motion of the spool valve caused by the input drive signal. The force developed in the feedback chamber is proportional to the rate of change of the drive signal to the torque motor; the greater the rate of change of the drive signal, the greater the instantaneous feedback pressure.

Hydraulic servo valves and actuators are precision devices. The parts are delicately balanced and can easily be damaged by rough treatment and contamination. The torque motor, for instance, can be ruined by tapping it with a screwdriver handle. The components must be handled with care; avoid dropping or jarring, and take care to prevent wrenches and other tools from striking them. When replacing hydraulic components, extreme care must be exercised to prevent contamination of the system. The necessity for cleanliness cannot be overemphasized. The spool valve and the small filters within can be jammed or damaged by dirt. The valve can become prematurely loaded by contamination introduced through careless handling. Even the tiniest particle from a person's finger can completely block the servo valve and precision orifices. These orifices are as small as a human hair, and they do not have to be completely blocked to destroy their operation.

SUMMARY

This chapter has provided information on servosystems used in naval aircraft. The information, for the most part, is of a basic nature and is applicable to all Navy aircraft systems. The following is a summary of the specific points in the chapter.

BASIC SERVOMECHANISMS—The essential components of a servomechanism are a data transmission system, a servocontrol amplifier, and a servomotor.

The functions of the data transmission system are as follows:

1. To measure the servo output.
2. To transmit or feedback the signal, which is proportional to the output.
3. To compare the input signal with the feedback signal.
4. To transmit to the servoamplifier a signal which is proportional to the difference between the input and output signals.

The functions of the servoamplifier are as follows:

1. To amplify the error signal provided by an error detector.
2. In some cases, to transfer the error signal into suitable form for controlling the servomotor or output member.

(It may also include provisions for controlling the servomotor or output member.)

The servomotor functions to position the servo load. The motor must be capable of positioning the load so as to require a minimum response time based on the requirements of the system.

SYNCHRO DATA TRANSMISSION—A synchro data transmission system is comprised of a synchro transmitter, a synchro control transformer, and in some cases, a differential transmitter for additional servo inputs. The synchro transmitter transforms the motion of its shaft into electrical signals suitable for transmission to the synchro control transformer, which comprises the error detector.

MULTIPLE-SPEED DATA TRANSMISSION SYSTEMS—Multiple-speed systems transmit a wide range of data at different speeds and still maintain a high degree of accuracy. To indicate the number of different speeds at which data is transmitted, refer to the system as being a single-speed, dual-speed, or tri-speed system.

OUTPUT DEVICES—The output of a servocontrol amplifier is fed to an output device. The functions of this device, usually a servomotor, are to supply torque, power, and dynamic characteristics required to position a servo load.

In aircraft weapons systems, the electric motor is most frequently used as an output device. However, electromagnetic clutches, hydraulic devices, and pneumatic devices are also used.

ZEROING SYNCHRO UNITS—For a synchro transmitter or receiver to be in a position of electrical zero, the rotor must be aligned with S2, the voltage between S1 and S3 must be zero, and the phase of the voltage at S2 must be the same as the phase of the voltage at R1.

The most common methods of zeroing transmitters and receivers are the ac voltmeter method and the electric lock method.

ANTENNA POSITIONING SERVOSYSTEMS—A servosystem is used to position a radar antenna and supply target information to associated weapon systems. The system can be operated in a search mode of operation or a track mode of operation.

The search mode provides a scan pattern which is used to locate targets. In the track mode of operation, the function of the antenna servosystem is to position the antenna based on the video ouput of the radar system. The positioning of the antenna is such that it follows the target.

CHAPTER 4

DATA SENSING ELEMENTS

In the previous chapter, you learned about various synchros and servosystems and how they are used. This chapter describes elements that sense movement or changes in speed or direction. Two such elements (devices) are the accelerometer and the gyroscope.

In the previous chapter, we indicated that the information sensed by these devices must be translated and/or transmitted to other systems or devices in order for it to be useful information. We also indicated that the translation or transmission is, in some instances, a function of synchros and servosystems. Accelerometers and gyroscopes, however, are the sources for this type of information.

In modern naval aircraft, mechanical and electrical devices for sensing changes in direction, attitude, and acceleration are indispensable. Among the systems which depend upon such devices for their operation are the following:

1. Gyrocompass systems
2. Flight control systems
3. Radar and gun platform stabilization systems
4. Antenna rate tracking measurement systems
5. Inertial navigation systems

As we have indicated, two devices used to sense these changes are the accelerometer and the gyroscope. Let's get into the subject by first discussing acceleration.

ACCELERATION SENSING

Acceleration is defined as the rate of change of velocity; it is the change of velocity with respect to time. Velocity is defined as the rate of change of position; it is the change of position with respect to time.

Do not confuse velocity with speed. Speed is defined as the magnitude (amount) of velocity. Speed implies only magnitude while velocity implies both magnitude and direction. For example: 30 miles per hour is a speed; 30 miles per hour FORWARD is a velocity.

Accelerations are measured in "g" units. A "g" unit is a measurement of force using normal weight (as determined by gravity) as a reference.

Newton's second law of motion states that the acceleration (a) of a body is directly proportional to the force (F) applied to that body and inversely proportional to the mass (M) of that body. Thus

$$a = \frac{F}{M}$$

Assume that a 170 pound man is in an aircraft flying straight and level; the only force felt by him is his normal weight; he is experiencing 1g

$$a = \frac{170}{170} = 1\text{g Unit}$$

However, if the plane suddenly climbs (accelerates upward) he may feel a force of 510 pounds being applied to him; he is experiencing 3g's of vertical acceleration

$$a = \frac{510}{170} = 3g\text{'s}$$

If the aircraft enters a dive, he may suddenly feel weightless because the force applied to his body is less than the normal force of gravity; he is experiencing "0" g's

$$a = \frac{0}{170} = 0g\text{'s}$$

A device used to sense accelerations (changes in speed or direction) is called an accelerometer. Its output is usually in the form of a voltage proportional to the acceleration to which it is subjected. Accelerometers are utilized in weapon control systems to detect and to measure acceleration in any desired geometrical plane for such purposes as:

1. To provide information to a computer, whereby it may correct for gravity drop of a projectile when the aircraft is performing maneuvers other than straight and level flight

2. To provide information to a computer to aid in determining the release point during loft and toss bombing runs

3. To provide information to the gyroscopes used to maintain stable reference platforms to prevent the gyroscopes from precessing on false gravity inputs

You should be aware that the use of accelerometers in weapon control equipment is not limited to the three previously mentioned applications. The extent to which accelerometers and gyroscopes can be used is tremendous. In no way can this manual and the Navy Electricity and Electronics Training Series (NEETS) present all of their possible applications. You should, however, be able to relate the fundamentals presented in these two training series to the actual applications with which you are or will be involved.

THEORY OF OPERATION

Basically, an accelerometer consists of a mass suspended like a free swinging pendulum within a case. When the case and pendulum are traveling at a constant velocity, the pendulum remains in its center position. However, when the case is accelerated, the pendulum will appear to swing in the direction opposite to that of the accelerating force. It may also be said that the case tries to "outrun" the suspended mass, causing a change in the relationship of the mass and case.

In actual practice, the mass is held in its null or zero position with a calibrated spring or springs. To further dampen oscillations, the case is normally filled with a fluid. Since the deflection of the pendulum is proportional to the accelerating force, the amount of deflection (hence the accelerating force) is measured and transmitted to other units for use in the solution of the armament control problem.

Some common types of accelerometers are briefly decribed in Module 15 of NEETS, NAVEDTRA 172-15-00-80. The accelerometers described are the basic accelerometer, the E-transformer type accelerometer, and the pulse-counting type accelerometer. Let us expand briefly upon the NEETS presentation.

POTENTIOMETER TYPE ACCELEROMETER

The potentiometer type accelerometer (fig. 4-1) is used in present day aircraft in the solution of loft and over-the-shoulder bombing problems. It measures the gs pulled by the aircraft during a maneuver and aids immeasurably in determining the point of release of weapons. It is also used to aid in solving air-to-air gunnery and missile problems.

E-TRANSFORMER TYPE ACCELEROMETER

The E-transformer type accelerometer (fig 4-2) is used to detect excessive horizontal acceleration

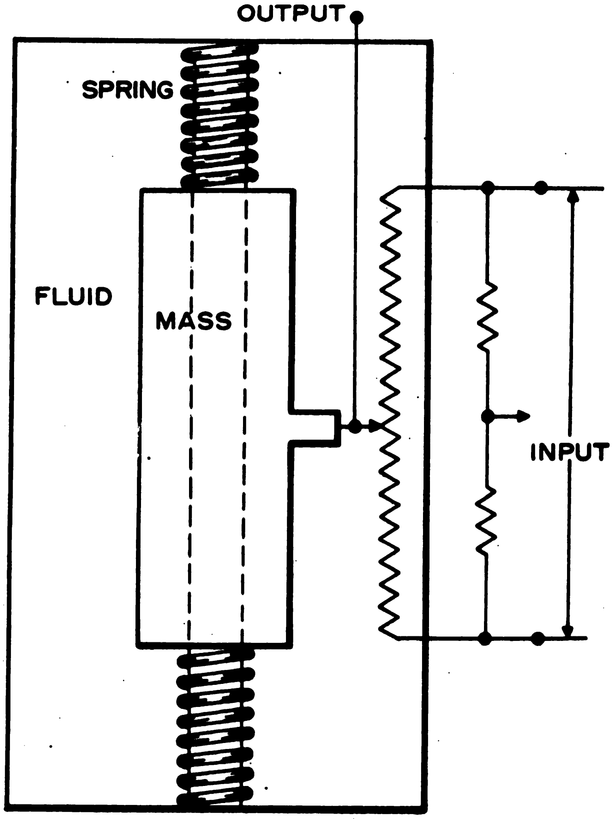

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Figure 4-1.—Typical potentiometer type accelerometer.

that could cause false gravity inputs to an aircraft's stabilizing gyroscopes. A normal installation utilizes two accelerometers. One is mounted parallel to and along the pitch axis of the platform to detect excessive accelerations along that axis. The other is mounted parallel to and along the roll axis of the stabilized platform for the purpose of detecting excessive accelerations along the roll axis.

FORCE BALANCE ACCELEROMETER

An accelerometer commonly used with inertial navigation systems is the force balance accelerometer. A force balance accelerometer is one that uses its output to return the sensing member to its null or rest positon. A schematic representation of this type of accelerometer is shown in figure 4-3. The pickoff coil, the mass,

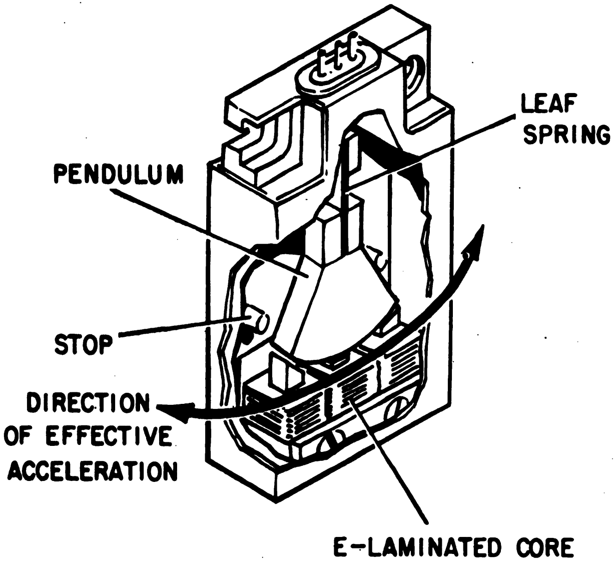

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Figure 4-2.—E-transformer type accelerometer.

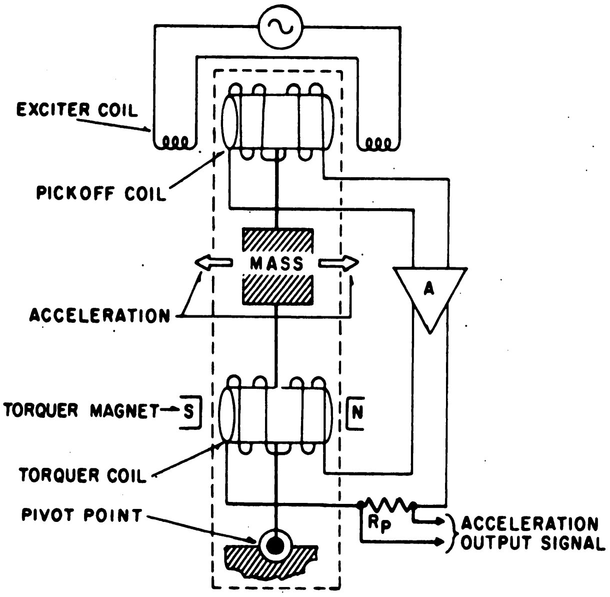

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Figure 4-3.—Force balance accelerometer.

and the torquer coils are all situated on a common movable shaft, which has the ability to make a partial rotation about its pivot point axis.

The amount of acceleration is detected by the pickoff coil. The output of the pickoff coil is amplified and used to torque the movable shaft back to its null position. The voltage drop across Rp is proportional to the measured acceleration and is the point where the acceleration output signal is picked off.

PULSE COUNTING ACCELEROMETER

Though the output of a force balance accelerometer is an analog current proportional to acceleration, there is need for some accelerometer output signals to be in digital form. Pulse counting accelerometers satisfy this need, since their pulse output can be supplied directly to computers. A schematic of a pulse counting accelerometer circuit can be seen in figure 4-4(A), while the cutaway view is shown in figure 4-4(B).

Normally, a minimum of maintenance is performed on accelerometers by the aviation fire control technicians. Maintenance usually consists of performing operating checks as prescribed by the maintenance instructions manual for the applicable equipment. Defective units should be replaced and forwarded to an overhaul shop where repair can be performed by qualified personnel using proper equipment.

GYROSCOPES

The gyroscope is the world's oldest mechanism. This is because the earth itself is a gyroscope. The earth's daily rotation about its axis has provided the stabilizing effect that has kept the North Pole pointed within 1° of Polaris (the North Star), probably since the beginning of time, but has definitely done so since the beginning of recorded knowledge. This stability of the earth's spin axis illustrates one of the basic properties of the gyroscope, and this same persistence in man-made gyros is the basis of many modern instruments.

The first manufactured gyroscope was built by a French physicist names Foucault. He used his gyroscope to show the effect of the earth rotating. The effect was in the form of apparent gyroscopic rotation (precession). Apparent precession is described in Module 15 of NEETS.

Foucault also named the gyroscope. The word gyroscope was derived from the Greek words "gyros," meaning revolution, and "skopein," meaning to view. These two words, when

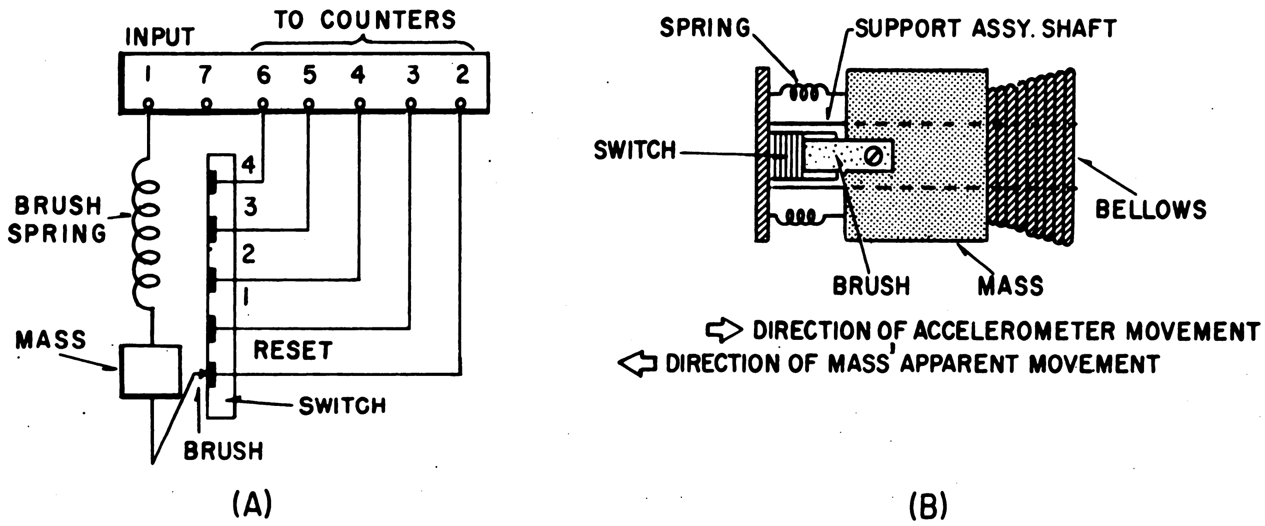

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Figure 4-4.—Pulse counting accelerometer. (A) Schematic diagram; (B) cutaway.

combined, mean "to view the revolution." His choice of this name was quite appropriate, since his invention made the rotation of the earth visible.

Incidentally, if you have not done so, you perhaps should refer to NEETS for the fundamentals of gyroscopic operation. You should be thoroughly familiar with such terms as "degrees of freedom," "rigidity," "precession," "apparent precession," and "gyro drift." If you are not, then very definitely you should review the NEETS module. With that thought in mind, let us relate gyroscopic operation to some practical considerations.

DEGREES OF FREEDOM

As pointed out in the NEETS module a gyro can have different degrees of freedom, depending on the number of gimbals in which it is supported, and the manner in which the gimbals are arranged. The term "degrees of freedom" as used with gyros is an indication of the number of directions in which the rotor is free to move.

A gyro enclosed in only one gimbal (fig. 4-5) has only one degree of freedom. This degree of freedom is at right angles to the axis of spin. Assume that this gyro is mounted in an aircraft with its spin axis parallel to the axis of travel. The rotor is spinning, and it is free to move from left to right (it has one degree of freedom). This gyro has no other freedom of movement. Therefore, if the aircraft should nose up or down, the plane containing the gyro spin axis would move exactly the same as the aircraft. However, if the aircraft should turn right or left, the gyro would not change its attitude, since it has a degree of freedom in these directions.

A gyro mounted in two gimbals normally has two degrees of freedom. Consider a rubber ball in a bucket of water. Even though the ball is supported by the water, it is not restricted as to attitude by the water, and can lie with its spin axis in any direction. Such is the case with a two-degree-of-freedom gyro (often called a free gyro). (The gyro in figure 4-6 is a two-degree-of freedom gyro.)

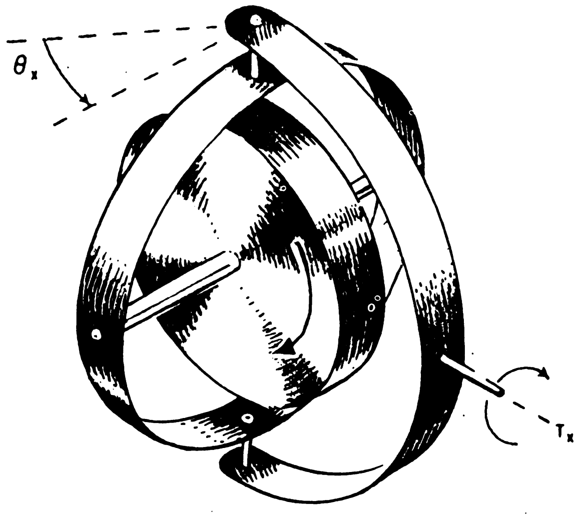

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Figure 4-5.—Single degree-of-freedom gyro.

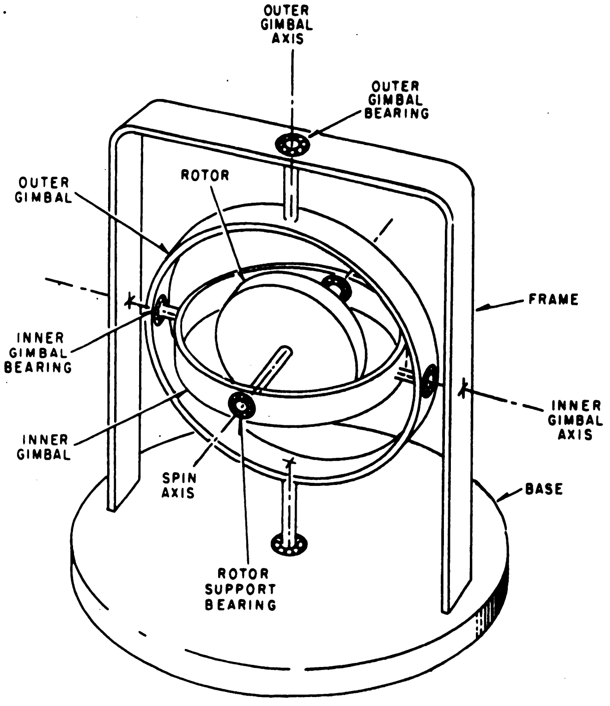

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Figure 4-6.—Two-degree-of-freedom gyro.

This means that if the base surface turns around the outer gimbal axis, or around the inner gimbal axis, the gyro spin axis stays put. In other words, the gimbaling system isolates the rotor from the base rotation.

ORIENTATION

Gyroscopic elements are oriented with the various axes of the aircraft. The manner in which this is accomplished depends, to a certain extent, on the equipment and the functions the gyros are expected to perform. Figure 4-7 illustates the three axes of an aircraft and their relationship to the gyro spin axis. With the gyro mounted as shown, the amount of pitch and/or roll of the aircraft can easily be measured, as the gyro will maintain a stable reference as the aircraft maneuvers.

Gyros may be oriented with any of the aircraft's axes and may also be used in combinations of two or more for determining rates and amounts of movement about any or all of the aircraft's axes. Therefore, to fully understand some of the weapon control equipment, it is necessary to understand the orientation of the gyro elements in the equipment and their relationship to the axes of the aircraft.

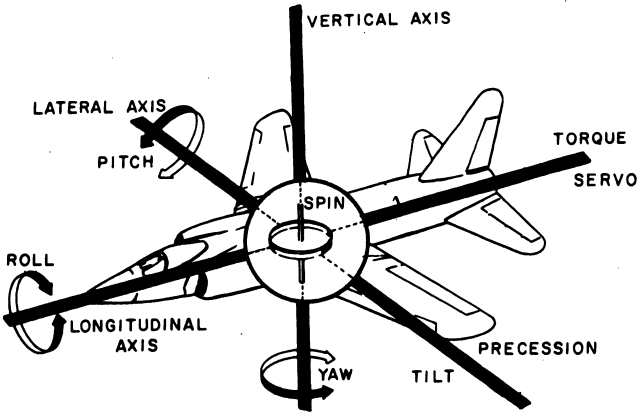

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Figure 4-7.—Relationship of gyro axes to the aircraft axes.

PICKOFF DEVICES

To utilize a gyro as a detecting device for solving aircraft armament control problems, it is necessary to adapt it with some type of pickoff device. This is necessary so that the desired information can be determined and transmitted to the desired unit. Some of the devices used for this purpose are E-transformers, potentiometers, and synchros. These devices were discussed in the last chapter.

GIMBAL LOCK

Gyros may become damaged in the aircraft as a result of the phenomenon known as gimbal lock, unless some method is used to prevent it. As was previously mentioned, gyros are usually mounted so that the spin axis, inner gimbal axis, and outer gimbal axis are mutually perpendicular during normal operation. This is the condition of the free gyro in an aircraft during straight and level flight.

When the aircraft maneuvers, however, the condition as described no longer exists. In order for the gyro rotor to maintain its position in space as the aircraft rolls, climbs, and dives, the gimbals must change their position relative to each other. The maneuvers performed by transport type aircraft present no problem. But in a fighter or attack type aircraft the maneuvers are often quite severe, and gimbal lock could be encountered.

Gimbal lock occurs when the spin axis and the outer gimbal axis coincide. This condition exists whenever the aircraft passes through the 90° climb or dive position. When gimbal lock occurs in a free gyro, it can no longer maintain its three degrees of freedom. Because the gimbals are locked, if the aircraft sustains a rolling motion, the gimbals are unable to compensate for it and the gyro tumbles; that is, the gyro spins end over end, and the reference is lost.

If a perfect loop were executed, that is with no yaw or roll, gimbal lock would be no problem. Such a loop is virtually impossible because of the aerodynamic characteristics of the airframe. Therefore, gimbal stop pins are generally used to prevent the spin axis from becoming aligned with the outer gimbal axis. When stop pins are used, the gyro simply precesses 180° as the aircraft goes through the 90° climb or dive position. Gimbal stop pins usually limit gimbal movement to angles of about 85° from the horizontal. This means that the gyro reference is lost while the aircraft is in the 85° to 95° position, but this is better than losing it entirely. In some applications, a fourth gimbal is used. It is called the outer roll gimbal. Should a perfect 90° climb or dive be accomplished, the outer roll gimbal would be driven 180° and, therefore, would prevent the spin axis from aligning with the outer gimbal.

APPLICATIONS

As pointed out in NEETS, gyroscopic instruments make use of the two basic properties of the gyro: rigidity in space and precession. Rigidity is used to establish a reference in space which is unaffected by movement of the supporting body; and precession is employed to control the effects of the Earth's rotation, bearing friction and imbalance, thus maintaining the reference in the required position.

For blind flying (in clouds, for example), an artificial horizon is essential. A free gyroscope provides the reference for the operation of the artificial horizon. In this case the spin axis is made vertical before takeoff or during contact flying and is called a vertical gyro. The gyro then maintains the reference for a period of time, depending on its precision of construction and length of time it is required to provide the reference.

A free gyro may also be used to provide an azimuth reference. The gyro is initially set with its spin axis horizontal and in some prescribed compass direction, such as north. When used in this configuration it is called a directional gyro. The gyro will maintain the preset direction reference for reasonable periods of time regardless of the attitudes of the aircraft.

A system called a stable platform usually requires the use of both a vertical and directional gyro in combination. Pickoffs on a stable platform measure deviation of the vehicle about three quadrature (mutually perpendicular) axes from a space stabilized coordinate system. On an aircraft these axes are called pitch, roll, and yaw. Auxiliary motors, controlled by the sensory signals, are used to move the platform about the three axes to keep the pickoff at or near zero.

RATE GYRO

A rate gyro may be defined as a device for detecting the angular rate of change of position of an object. In weapon control equipment, one major concern is the angular rate of change of a target aircraft. This rate of change of the target may be determined by measuring the angular rate of change of an antenna locked on the target. Target angular rate information may also be determined by measuring the angular rate of change of the attacking aircraft while tracking it.

There are two basic types of rate gyros used in aircraft weapon control equipment. One type senses a rate of change in one geometric plane while the other type senses a rate of change in two planes simultaneously. The latter type is capable of not only measuring rate of change in two geometric planes, but when supplied with range, ballistic, and other necessary information, is capable of determining the necessary lead angle required to hit the target. For the purpose of discussion, these gyros are referred to as one-plane and two-plane rate types.

The one-plane rate gyro is used quite extensively in aircraft weapon control equipment. This type is often used in pairs, one for detecting rate of change in elevation and one for detecting rate of change in azimuth. The purpose of this type gyro is to produce an electrical output signal that is proportional to the angular rate of gyro motion about the precession axis. It should be remembered that the rate of motion about the processional axis is proportional to the force applied about the torque axis.

A simplified rate gyro is illustrated in figure 4-8. In this case the platform represents the aircraft, and the telescope is the radar antenna assembly. As the telescope follows the target, the gyro attempts to align its spin axis with the axis of the applied rotation. This causes compression and stretching of the calibrated springs and displacement of the pointer. The amount of displacement is in direct proportion to the rate of change in the line of sight (LOS). Thus, this gyro is a rate gyro.

STABILIZING GYROS

A basic free gyro may be used as a stabilizing gyro by modifying the mounting and placing certain limitations on its movement. Unlike the rate gyro discussed previously, the stabilizing

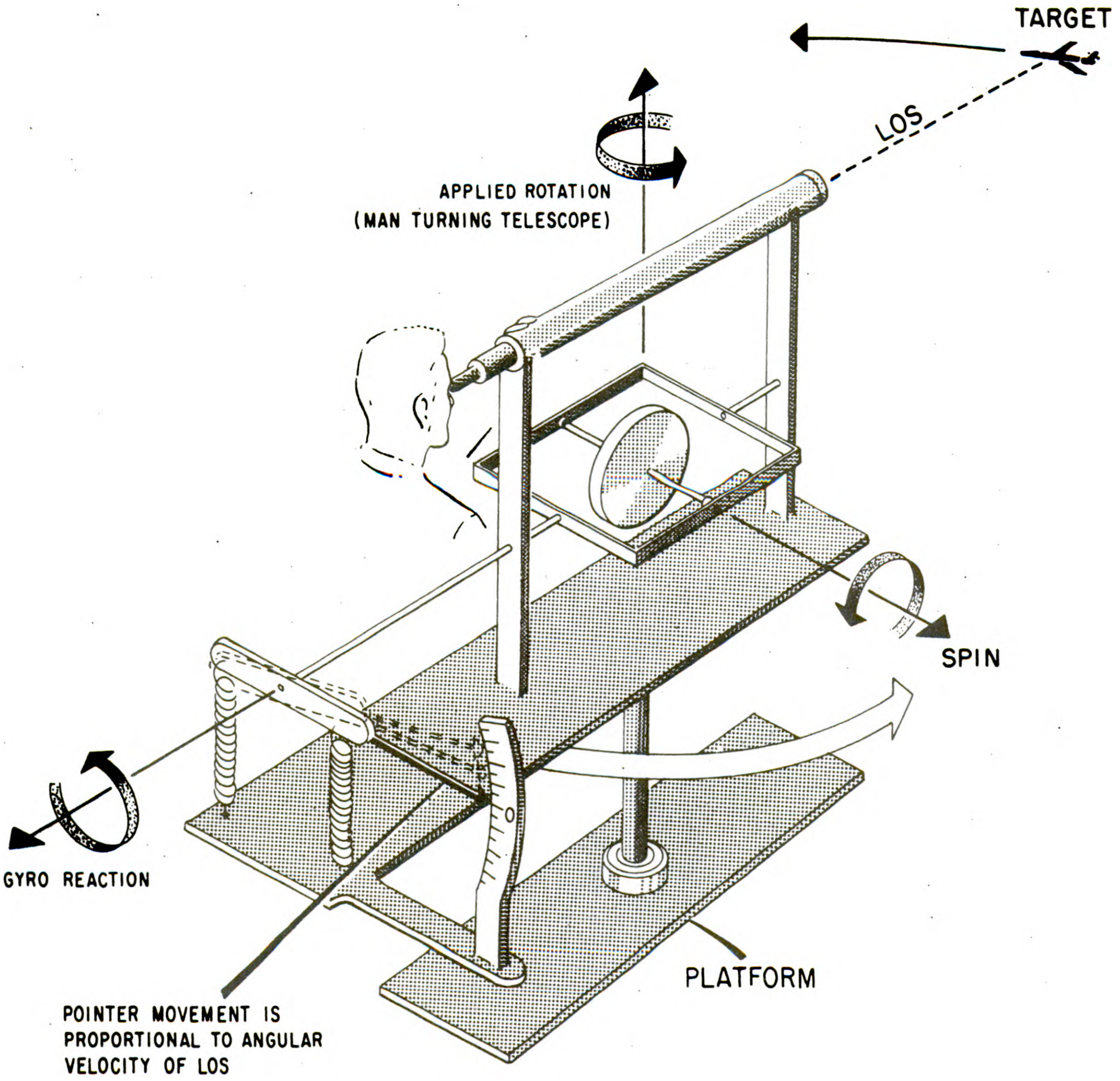

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Figure 4-8.—A simplified rate gyro.

gyro is used to establish a fixed reference from which it is possible to measure amounts of movement or displacement. Stabilizing gyros may be used to establish either horizontal or vertical references, and may be used in groups of two or more to establish geometric planes of reference. A typical application of a stabilizing gyro may be found in a weapon control system where it is used to stabilize the radar antenna and measure the amount of roll of the aircraft for use in missile guidance.

In addition to the basic components of a free gyro, a stabilizing gyro has provisions for detecting any deviation from the stabilized reference and transmitting this information to the equipment as required. It normally has some means of erection or aligning its spin axis with a predetermined reference. A stabilizing gyro may also include a means of caging; that is, restricting or locking its gimbals.

GYRO MAINTENANCE

The maintenance of gyros is usually restricted to overhaul activities. Some gyros, such as rate gyros, may be sealed and any malfunctions are corrected by replacement.

The gyros used in stable platforms are usually also replaced rather than repaired when malfunctions occur. However, this does not preclude the maintenance, adjustment, and repair of associated parts such as erection devices, synchros, and torque motors, and replacement of devices such as accelerometers and E-transformers normally found in such a stable platform. The electronic circuits found with the gyro may also be repaired. In all cases, the maintenance instructions manual specifies the extent of repairs that may be attempted at a specific level of maintenance. Pitch, roll, and balance adjustments are covered in Chapter 3 of this manual under antenna servosystems.

SUMMARY

As has been presented in this chapter, there are two basic types of devices which sense changes in direction, altitude, and acceleration. These are the accelerometer and gyroscope.

THE ACCELEROMETER can be one of a variety of types. These include the potentiometer, the E-transformer, the force balance type, or a pulse-counting type.

RIGIDITY and PRECESSION are two properties of a gyro. Rigidity is used to establish a reference in space which is unaffected by movement of a supporting body. Precession is used to control the effects of the Earth's rotation.

A FREE GYROSCOPE provides the reference for the operation of an artificial horizon. A free gyroscope may also be used to provide an azimuth reference.

GYROSCOPES are also used in stable platforms. Pitch, roll, and yaw data are obtained from stable platforms.

CHAPTER 5

WEAPON CONTROL FUNDAMENTALS

In this chapter, we discuss the basic weapon control problem and its variations. As an AQ or as a technician interested in weapon control, you should be aware of what happens to the weapon or projectile after it has been released or launched. This chapter defines some of the terms and presents some of the problems encountered in aircraft weapons systems. Let's consider the primary problem first.

PRIMARY PROBLEM

The primary problem of aircraft weapons systems is to accurately determine the correct position and attitude in which to place the aircraft in order to be reasonably sure of making a hit on the target. The problem presents itself in varying degrees of difficulty, depending on the type of weapon used, the type of attack, and whether the target is airborne or on the surface. In almost all cases, this requires the generation of what is known as lead angle.

Lead angle can be in either elevation or azimuth, or a combination of both. For example, a duck hunter knows in order to hit a fast moving bird, the weapon must be aimed ahead of and above the bird. In so doing, a lead angle is established which is a combination of elevation lead angle (to compensate for the gravity drop of the shot) and azimuth lead angle (to compensate for the distance the bird travels while the shot travels from the weapon to the bird). Lead angle (fig. 5-1) is a term used to describe the angle which lies between a straight line extending from the weapon to the target, and a line projected from the centerline of the weapon.

No matter how difficult or how simple the problem may be, there are two terms that always present themselves in the solution of the problem: One is ballistics; the other is trajectory.

BALLISTICS

Ballistics is a term which refers to the science of the motion of projectiles. It is a study of all the various forces, both controllable and uncontrollable, which govern the movements of projectiles.

The study of ballistics is normally divided into two branches, interior and exterior. The study of interior ballistics is primarily concerned with the movement of projectiles inside a gun barrel or bore. The study of exterior ballistics is concerned with the motion of the projectile after it leaves the bore of the gun or the launcher and is free in the air.

Interior ballistics is covered by a great number of highly complicated technical subjects which are of little concern to you. However, to gain an insight into how some of the interior ballistic factors affect exterior ballistics, we briefly discuss the subject.

The factor having the most effect on interior ballistics is probably the propellant. Broadly speaking, there are two classifications of explosives. They are the high explosives as used in bombs and which burn at an extremely rapid rate (detonate), and the slower (controlled) burning explosives. These slow burning smokeless powders (propellants) burn smoothly and progressively, giving lower pressure, for instance, in the chamber of a gun. The pressure, however, is maintained for a longer period of time. Thus, the projectile is literally pushed into its trajectory.

In rockets and missiles, controlled burning is also utilized. In this type of application, the

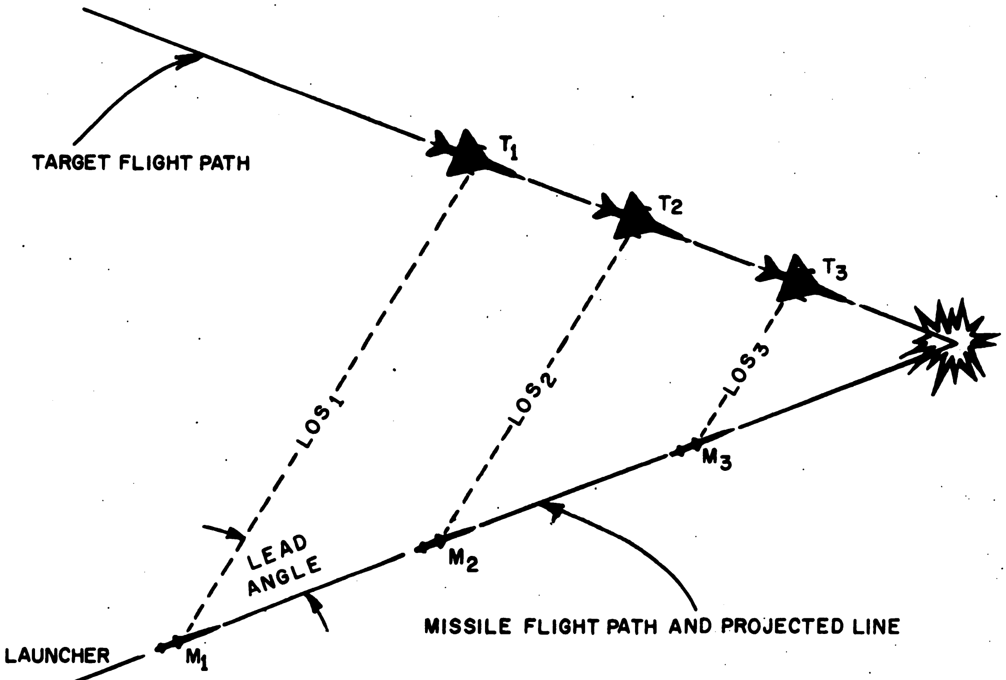

Figure 5-1.—Lead angle and projected line of a weapon to a target.

projectile accelerates until its fuel is consumed. This is usually referred to as burn time.

Another item of interior ballistics of concern to you is the fact that all aircraft guns are rifled the length of the bore. Rifling is the process where spiral grooves are cut in the inside walls of the gun bore. The projectile fits tightly in these grooves, and a spinning motion is imparted to the projectile as it moves down the bore. The rifling is usually constructed so as to give the projectile a clockwise rotation as viewed from the rear of the gun. We discuss the effects of spinning motion later in this chapter.

Exterior ballistics is the branch of ballistics with which you are most concerned. However, to fully understand exterior ballistics, you must fully understand the term, trajectory.

Trajectory may be defined as the curve a projectile describes in space. For guns, trajectory is from the muzzle to the first point of impact. For rockets and missiles, the actual ballistic trajectory is that portion of the distance to the target under free flight (after burn time); and for bombs, it is from the time of release to the time of impact.

The determination of the trajectory of a projectile with certain physical characteristics and velocity forms the primary problem of exterior ballistics. Your primary concerns are the factors which determine the trajectory of projectiles in air-to-air and air-to-ground attack problems.

FACTORS AFFECTING TRAJECTORY

We now discuss the factors that affect a trajectory. The projectile described in the majority of our examples is that of a gun. However, most of the forces that affect the gun projectile also have the same effect on the bomb, rocket, or missile during free flight. Some of the factors have more effect than others, but all must be taken into account if an attack on a target is to be effective.

Gravity

Gravity is one of the major factors, since it starts acting on the projectile as soon as it is free in the air. The gravity drop of a projectile in flight varies during time of travel. The longer a projectile travels from the gun to the target, the longer gravity influences it. The time of travel varies with projectile speed and distance to the target. Therefore, the longer the distance to the target and the slower the projectile, the greater the gravity drop.

Gravity drop is computed by the formula:

$$s = 1/2\ gt^2$$

where

s = the distance traveled

g = the acceleration of gravity (about 32 ft/sec/sec)

t = the time of fall in seconds

This formula was developed for conditions in a vacuum, but is sufficiently accurate for computing trajectories of projectiles in still air.

Consider the case of a projectile leaving the muzzle of a gun and traveling 2,000 yards horizontally in 3 seconds. Ignoring all other factors but the effect of gravity, compute the distance that the projectile would fall.

$$s = 1/2\ gt^2$$

$$s = 1/2 \times 32 \times 3 \times 3$$

$$s = 144 \text{ ft}$$

Thus, the projectile would fall 144 feet in 3 seconds. This effect is illustrated in figure 5-2.

From the preceding it should be apparent that the weapon must be elevated to hit a target that is in the same horizontal plane.

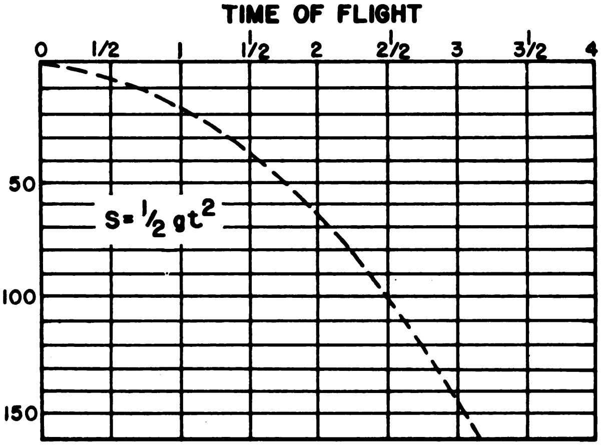

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Figure 5-2.—Gravity drop of a projectile.

Air Density

Air density is one of the factors which contributes to the resistance offered by the air to the flight of a projectile. Cross sectional area and velocity of the projectile are other factors in the determination of the amount of air resistance. The effect of this resistance is the deceleration of the projectile which is more pronounced in the early part of the trajectory. This is due to the higher velocity of the projectile at that time.

It has been found that the denser the air mass, the greater the friction offered to the projectile; also, the larger the cross sectional area and the higher the velocity, the greater the friction. The longer the distance of travel of the projectile, the greater the effect of air density upon the trajectory of the projectile. Therefore, the further the projectile travels, the slower it travels.

Due to the effects of gravity, a projectile fired horizontally from a high-flying aircraft would start to drop immediately on leaving the muzzle; and the horizontal component of velocity would start to decrease immediately due to air friction. Eventually the projectile would be falling straight down. In falling, the body falls faster and faster until the deceleration due to friction equals the acceleration due to gravity. Then the body continues toward the earth from that point at a constant rate of speed.

Air density is a factor that determines the curve traced by the projectile in its transition from horizontal to vertical flight. The final velocity of the projectile in its downward flight is also a function of air density. The importance of downward velocity can be appreciated when considering the time consumed in the drop of a bomb from any specified altitude. The time of drop is important in the determination of release point.

Among the factors that cause variation in the atmospheric density are variations due to changes in temperature and pressure, variations due to changes in altitude, and variations due to changes in moisture (relative humidity). The density of the atmosphere at a level above the earth's surface depends both upon the density at the surface and the altitude of the given level, since both temperature and pressure decrease with altitude. Because of fluctuations in air density caused by air currents or other influences at different heights, air density at any specific height cannot be expressed as a relationship between altitude and surface density.

The only accurate means of determining air density at any certain altitude is the actual measurement of temperature and barometric pressure. Most aircraft weapon control systems have the means for continuous measurement of both temperature and pressure.

It is commonly accepted that the retardation of a projectile varies directly in proportion to the density of the air. Therefore, regardless of cause, a given percentage variation in air density has measurable effect upon retardation of the projectile. The amount of retardation due to air resistance helps determine the time of flight of a given projectile for a specified distance.

Figure 5-3 shows three relationships between time of flight of a projectile and relative air density. A study of this graph is worthwhile, not only to show the relationship between the variable factors, but also to familiarize you with the use of this type of graphical representation.

Notice that there are three variable factors in figure 5-3. They are the time of flight along the vertical axis, the relative air density along the horizontal axis, and the future range (R_f). Future range (R_f) is the distance the projectile travels to the actual point of impact. This distance may be more, less, or the same as the present range (R_p), depending on whether the range of the target is increasing (opening), decreasing (closing), or remaining the same with respect to the launching aircraft. The difference between present range and future range is the amount the range changes during the time of flight (t_f) of the projectile.

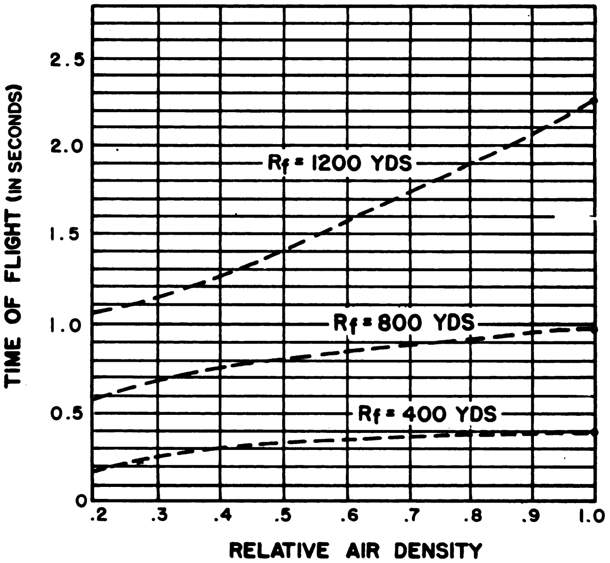

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Figure 5-3.—Relationship between air density and time of flight.

A change in future range is shown by a change in the actual curve used. All values along the 400-yard R_f curve are indications of time versus relative air density. For instance, when the range is 400 yards and the relative air density is 0.4, the time of flight is 0.3 seconds. The curve also shows that when the range is 400 yards and the relative air density is 1, the time of flight is 0.4 second.

If the range is 800 yards and the relative air density is 0.4, then the time of flight is approximately 0.75 second. Increasing the future range to 1,200 yards (top curve on graph), an air density of 0.4 results in a time of flight of 1.25 seconds.

An examination of the curves shows that the difference in time of flight for the 400-yard future range is comparatively small across the whole scale of relative air density. At the same time, the difference in time of flight for the 1,200-yard range with the change in air density is considerable. From this it can be concluded that if the aircraft armament control equipment is to be used on short firing ranges, it may not be necessary to continually correct for changes in relative air density. At longer ranges, however, air resistance does affect time of flight and therefore lead angle, which is dependent on time of flight. Compensation is also necessary for the effect of gravity. The greater the air resistance, the longer the time of flight, and the longer the projectile's path is altered by the effects of gravity.

If an armament control equipment is to be used at various air densities for controlling projectiles with comparatively long future range, the necessity for continuously measuring air density is apparent.

Airspeed and Initial Velocity

The airspeed of the aircraft must also be taken into account when determining the trajectory of a projectile. In forward-firing guns, airspeed is added to the initial velocity of the projectile. Initial velocity is a term often used to indicate the velocity of the projectile at the time it leaves the muzzle (muzzle velocity). The forward motion of the aircraft also affects rockets and missiles at time of launch, but other factors are involved in these problems and are discussed later.

It is easy to see that if a projectile were fired dead ahead, its total velocity (with respect to the ground) would be its initial velocity plus the speed of the aircraft. If a projectile were fired dead astern, the total velocity would be the initial velocity minus the speed of the aircraft.

Since the airspeed of the aircraft affects the velocity of the projectile, it apparently must also affect the trajectory. Airspeed affects trajectory because it is one of the factors that determines the time of flight of the projectile from the gun to the target. As before, the time of flight determines the time the projectile is influenced by the force of gravity.

As an Aviation Fire Control Technician, it would be reasonable for you to expect a control or automatic device to compensate for the effect of airspeed on trajectory. Such is the situation. Armament control equipment for forward-firing weapons have automatic systems for compensating for airspeed. Automatic means a system that, self-acting, will detect and note changes in aircraft airspeed, and include these changes in the solution of the problem.

Temperature

Temperature is usually not a primary factor in the consideration of a surface gunnery trajectory. Because of the wide ranges of atmospheric pressure and temperature encountered by the aviation gun platform, unlike the surface platform, temperature is one of the factors to be considered in aerial gunnery. The density, pressure, and temperature at 30,000 feet are considerably different from surface conditions.

Effects from changes in temperature are usually secondary in nature, in that atmospheric temperature variations play a part in the determination of one or more of the primary factors of air-to-air trajectory. Because of the wide variations, some types of aviation armament equipment do measure and use atmospheric temperature information in the solution of the trajectory.

As pointed out previously, air density changes with variations in temperature. One method used to measure air density is to measure both atmospheric temperature and pressure. When both of these factors are measured, they are combined in an electronic circuit which has air density as its output.

Temperature may be measured by one of several different means. One method is to calibrate changes in a liquid pressure utilizing the principle that most liquids contract with a decrease and expand with an increase in temperature. Another method is to measure temperature changes by means of an electrical circuit with a resistor sensitive to air temperature. As the resistance of the resistor varies with temperature, it results in a change in the amount of current in the circuit. The amount of current can be used to actuate a recording or computing device.

Measurement of temperature also plays a part in the determination of true airspeed which is a necessary factor in both air-to-air and air-to-ground trajectory. Airspeed is measured by determining the difference between Pitot pressure and static or barometric pressure. Pitot pressure is received from the Pitot tube and is the impact pressure of the airstream as the aircraft moves through the atmosphere. This Pitot pressure is compared with static pressure to determine airspeed. Because temperature will affect air density and air density affects pressure received from the Pitot tube, free air temperature must be applied to change indicated airspeed to true airspeed. True airspeed is the factor of direct importance in establishing the trajectory of airborne projectiles.

Gyroscopic Action

As previously mentioned, all aircraft guns are rifled (fig. 5-4) the length of the bore in order to impart a spinning motion or rotation to the projectile. This spinning stabilizes the projectile in flight. The grooves and lands of the rifling are constructed to give a clockwise rotation to the projectile, as viewed from the rear of the gun. Since a rotational motion is imparted to the projectile during its progress down the bore, the projectile in free flight becomes a gyroscope. It attempts to obey all the laws of the gyroscope. The operation of the gyroscope is described in Chapter 4 of this manual, and in Module 15 of Navy Electricity and Electronics Training Series (NEETS), NAVEDTRA 172-15-00-80.

A rotating projectile during flight is subjected to a force which causes it to drift. Drift (fig. 5-5) is the sideward curving of the point of fall from the original plane of fire. This deviation is due entirely to the effects set up by the rotation of the projectile. There are other lateral deviations that have an effect on some projectiles. Wind is an example of these deviations. However, they should not be confused with pure drift. While there is no complete agreement as to some of the details, generally there are three accepted causes of drift in an elongated projectile. They are as follows:

1. The gyroscopic action of the rotating projectile
2. The action of the air adhering to the projectile
3. The cushioning effect of air banking on one side of the projectile

The latter two cases are generally thought to have only very minor effects as compared to the first.

The gyroscopic action of the projectile while spinning in flight tends to keep the projectile's axis in the direction of the line of departure from the gun. However, the center of gravity of the projectile in flight tends to follow the curved path of the trajectory. The instantaneous direction of its motion at any point is that of the tangent to the trajectory. Air resistance opposes the flight of the projectile and works against its underside with greater force than elsewhere as shown in figure 5-5. The air resistance tends to push the nose of the projectile up.

An overturning or tumbling motion results as the center of gravity and an extension of the center of pressure to the axis of the projectile becomes further separated. However, the gyroscopic force of the projectile opposes this upsetting or

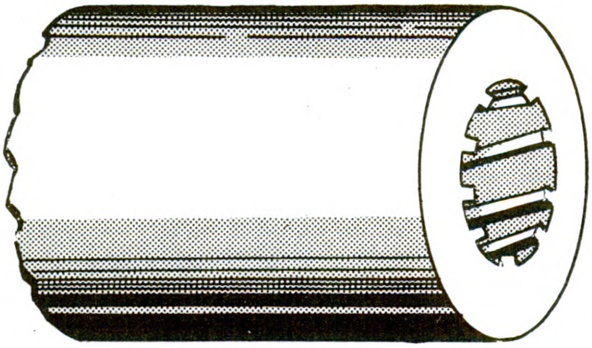

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Figure 5-4.—Aircraft guns rifled bore.

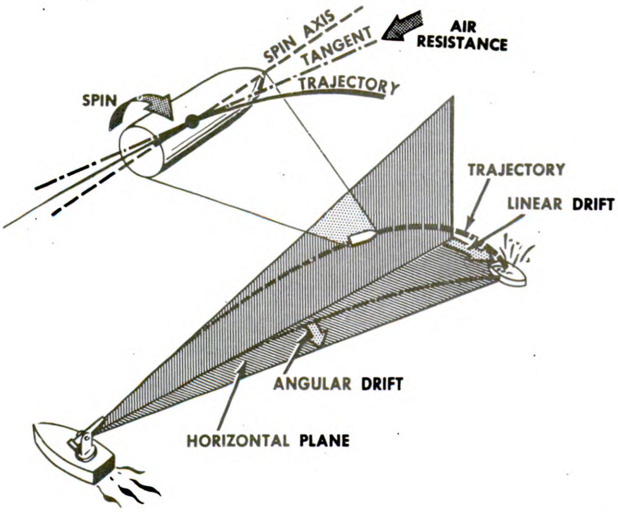

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Figure 5-5.—Projectile drift caused by gyroscopic action.

overturning moment and tends to keep the axis in the original direction. This gyroscopic moment which opposes the upsetting moment, in accordance with the laws of the gyroscope, causes a precession of the projectile about the direction of the force as it tries to overcome the tendency of the projectile to overturn. Also, according to the laws of the gyroscope, the precessional revolution of a projectile having a right-hand spin must be clockwise when viewed from the rear. This precession moves the nose to the right; and air resistance, working on the left side of the nose, forces the projectile to the right. This motion to the right is drift.

Wind

Some of the preceding effects upon trajectory are reserved for consideration of projectiles propelled from guns. Among these effects are the muzzle velocity and the rotation of the projectile. Others of the previously discussed effects have their influence on all types of projectiles. Gravity and air resistance will affect not only gun-propelled projectiles, rockets, and missiles, but also bombs. However, wind fits into an entirely different category because it must be considered in the air-to-ground problem but not in the air-to-air problem. Wind is defined as the motion of the air relative to the Earth.

AIR-TO-AIR TRAJECTORY.—Because of the relatively short distances involved and the short time of flight of projectiles in the air-to-air problem, the effects of atmospheric wind are not a factor in the determination of the trajectory. This may be visualized by considering the wind as a block of air (a frame of reference) containing both the target and the gun. If both the target aircraft and the aircraft containing the gun or rocket launcher are in this mass of air, they are affected equally and in the same direction when considered with respect to the ground.

If considered only in respect to each other and the mass of air, there is no change in their relationship caused by the movement of the air mass. As an analogy, consider a fly in a closed, moving automobile. The movement of the automobile does not affect the relationship of the fly and any object in the interior of the automobile. In the same manner, any projectile propelled from an aircraft toward another airborne target will be unaffected by the movement of the air mass through which the projectile is moving. This lack of effect is not true for projectiles launched from surface platforms or from airborne platforms and directed against surface targets.

AIR-TO-GROUND TRAJECTORY.—In bombing ground targets from an aircraft, the bomb is released without any propelling force. As it travels through the air, the forces of gravity and air resistance act upon it. The initial velocity of the bomb is the true airspeed of the aircraft. The trajectory of the bomb is determined by the effects of gravity and air resistance. If a wind were blowing, it would also act upon the bomb and would cause it to drift with respect to the ground. This drift could become a serious factor in bombing.

In order that the effects of wind on a bomb trajectory have more meaning, let us briefly discuss some of the aspects of the bombing problem. A more complete discussion of the bombing problem is provided in Chapter 6 of this manual.

Let's begin this discussion by considering an imaginary situation—the release of a bomb in a vacuum from an aircraft. The motion of the bomb imparted by the moving aircraft, plus the time of fall, determines the range. Range is the total horizontal distance the bomb moves forward from the place of release until impact. In this theoretical case, there are only two forces acting on the bomb. These are gravity and the motion of the aircraft. The bomb, theoretically, will be directly beneath the aircraft at the time of impact.

Since it is necessary to consider air resistance in order to deal realistically with the problem of trajectory, it is necessary to cover the problem of trajectory in air. What we are really saying is that there will be, at the very least, four forces acting on the bomb. These forces are the force of gravity, the air resistance in a vertical direction which opposes the pull or force of gravity, the motion imparted to the bomb by the aircraft, and the air resistance in the horizontal direction which opposes the forward motion of the bomb. The air resistance in the vertical direction causes the bomb to decrease in velocity at any instant during its fall, and thereby increases its time of fall.

The longer the time of fall, the longer the bomb is subject to the force of the wind. Air resistance in the horizontal direction causes the bomb to trail behind the vertical of the aircraft. In other words, when the bomb reaches the point of impact, it will not be directly beneath the aircraft.

With a constant airspeed and course, the horizontal distance that the bomb has lagged behind the aircraft at the instant of impact is called trail. The amount of trail is governed by the aircraft's airspeed at the time of release and the length of time the air resistance acts on the bomb. The amount of air resistance is determined by the air density (hence, the altitude) and the bomb's physical characteristics (shape, weight, and size). It is important to note that these three factors which determine trail, airspeed, altitude, and bomb characteristics are unaffected by the presence of wind. Therefore, trail is independent of wind and has the same value in a head wind or a tail wind that it has in still air. Trail and range are shown in figure 5-6.

The principal effect of winds along the line of the heading of the aircraft (that is, either head winds or tail winds) is the change made in the closing speed of the aircraft. Assuming that the target is stationary, if there is no wind, the closing speed is equal to the true airspeed of the aircraft. In a head wind, the closing speed equals true airspeed minus wind velocity. In a tail wind, closing speed equals true airspeed plus wind velocity. The trail value remains unaffected and is the same for all three cases. The reason for this is apparent when it is realized that the closing speed of the bomb is the same as that of the aircraft at the moment of release.

When the aircraft is headed either directly into the wind or downwind, its course over the ground is the true course flown. In other words, it makes its own course good over the ground. In all other instances, the course steered is not the actual course over the ground. There is an angle formed between the course the aircraft is steering and the course it makes good over the ground. This angle is called the angle of drift, and is shown as the angle between the aircraft heading and aircraft path in figure 5-7.

Associated with the angle of drift is another factor called crosstrail (fig. 5-7). Crosstrail is the distance the bomb falls toward the downwind side of the target due to the combination of drift angle and the natural trail of the bomb. To compensate for crosstrail, it is necessary for the aircraft to fly a course which takes it to the upwind side of the target a predetermined amount or distance which corresponds with the amount of crosstrail existing.

Wind also affects the trajectory of a rocket fired at a surface target. The rocket's time of flight for a given range determines, in part, the extent to which the trajectory is affected by wind. As with other projectiles, the time of flight is determined by the velocity, the range, and the air resistance.

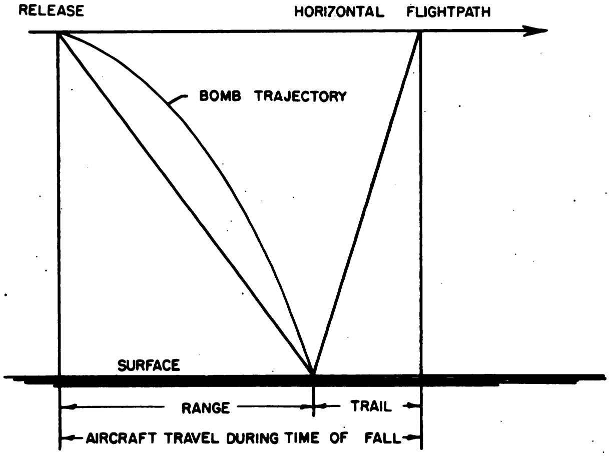

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Figure 5-6.—Horizontal bombing trail and range.

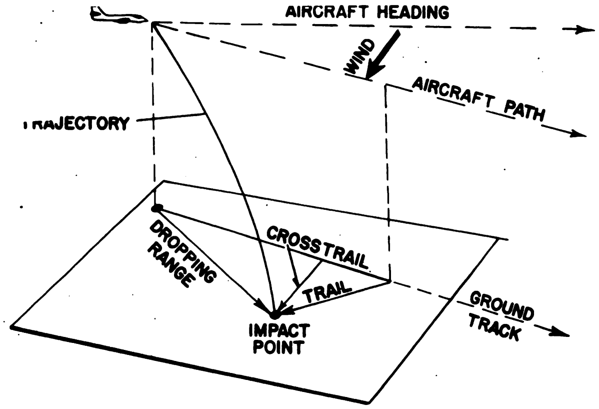

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Figure 5-7.—Effects of crosswind on bomb trajectory.

The influence of wind on an aircraft at the firing altitude causes it to drift. This motion is retained by the rocket when it is fired. The magnitude of drift for a rocket with a given time of flight varies with direction of the wind relative to the aircraft's heading, wind force, and angle of dive.

In computing the aiming allowances for wind, it is assumed that the air moves as a body with the same speed and direction at all altitudes. The effect of wind can be visualized by considering the air as a stationary mass and the earth as moving with the velocity of the wind. Thus, it is obvious that the wind causes the impact point on the earth to move a distance equal to the product of the time of flight and wind velocity. This also serves to illustrate that the aiming allowances for wind and target motion are the same magnitude.

Because wind does affect the trajectory of the rocket in its course from aircraft to target, aiming allowance must be used to compensate for the effect. A crosswind deflects a rocket the full amount of wind velocity multipled by the rocket's time of flight, regardless of dive angle. Compensation for a crosswind then requires full wind aiming allowance.

An oblique wind (fig. 5-8) is defined as one from such a direction that its apparent path in the sight is midway between the horizontal and vertical crosslines. An oblique wind exerts only part of its force in changing the course of the rocket. The shallower the dive, the less the rocket is affected and the less aiming allowance required. The steeper the dive, the greater the effect and aiming allowance approaches that for a crosswind.

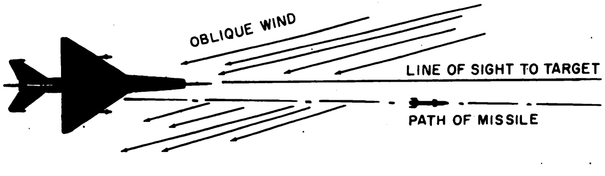

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Figure 5-8.—Effect of oblique wind on path of a rocket.

Angle of Departure

As previously mentioned, trajectory is the curve a projectile describes in space as it travels through the air on its way to the target. The origin of a trajectory is the position of the center of gravity of the projectile at the instant it is released. The tangent to the trajectory at its origin is known as the line of departure. The angle that the line of departure makes with the horizontal is the initial angle of inclination of the trajectory and is called the angle of departure. These terms are illustrated in figure 5-9.

Consider once again the imaginary situation of a projectile fired in a vacuum. The trajectory is shown in figure 5-9. The projectile has two motions. One is the motion along the line of departure at a speed equal to the initial velocity, and the other is the effect of gravity, a falling motion straight down at a constantly accelerating speed. At the instant the projectile leaves the gun, it starts to fall. It falls slowly at first, so most of its motion is upward and forward along the line of departure. As it travels farther, it falls faster, until the falling speed equals the upward speed along the line of departure. This is the highest point or the middle of the projectile's path. As it continues to fall, gravity pulls it down faster than momentum (always constant in a vacuum)

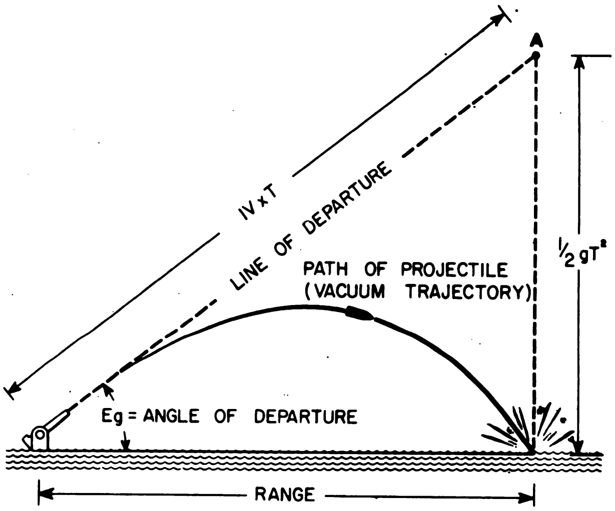

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Figure 5-9.—Path of projectile (vacuum trajectory).

is carrying it up. Its path curves downward more and more steeply, until it finally hits the surface.

The distance from the weapon to the point where the projectile hits the surface is the range of the weapon at that particular elevation. The range changes at different elevation angles. When the tilt of the line of departure is moved upward, the projectile's initial velocity tends to carry it higher. Thus, the projectile has farther to fall before it hits the ground. The reason is that it takes longer for the projectile to fall to earth, and during this longer time it has a chance to go farther forward.

As angle E_g (fig. 5-9) is increased due to the gun being elevated, the projectile is given more upward movement. Of course, it is also given less forward movement. When this angle is increased above 45°, the time the projectile is traveling continues to increase, but the forward movement will be so much slower that, even in the longer time, the projectile will not go as far. Obviously, if the gun were directed straight up from a stationary platform, the range would be zero. Maximum range is obtained (in a vacuum) at an elevation of 45°. Some typical trajectories are shown in figure 5-10. Notice how the range varies with the different elevation angles.

As would be expected, the trajectory of a projectile is considerably altered by its travel through air. A comparison of the air trajectory and the vacuum trajectory is shown in figure 5-11. Air alters the shape of the trajectory in several different ways. The striking velocity of the projectile no longer equals its initial velocity. The angle of departure no longer equals the angle of fall. Range is greatly decreased. Also, as pointed out previously, the projectile acts like a gyroscope. All these factors must be considered in aiming the gun. Some of the latest equipment measure and compensate for each factor. Other types of equipment compensate for some factors but not all of them.

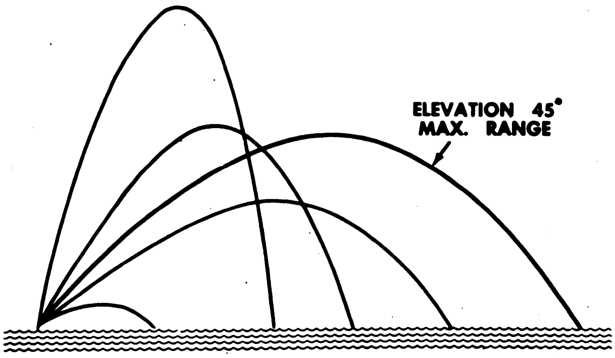

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Figure 5-10.—Effects of elevation on range in a vacuum.

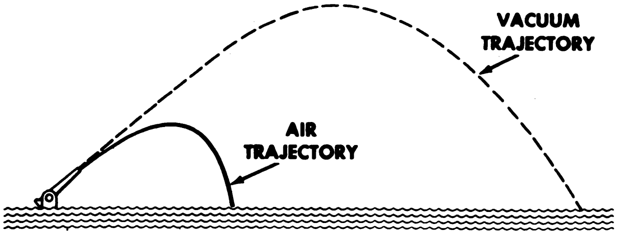

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Figure 5-11.—Vacuum and air trajectories.

For example, an accelerometer can be used to measure the g pull on the projectile at the time of release. If the angle of departure varies, the effect of pull of gravity on the projectile varies. Actually the force of gravity is the same regardless of the angle of departure, but the effects of gravity change with the angle of departure. The reason for this, as previously explained, is that the trajectory is the result of two motions: the forward motion and the downward motion. When the forward motion is reduced, then the trajectory is more influenced by the downward motion, gravity. Thus, the accelerometer measures the g pull on the projectile and modifies the gravity lead computation to compensate for this g pull.

The angle of departure is also important in determining the flightpath of air-launched rockets. The angle of the launcher in respect to the aircraft armament datum line determines the angle of departure of the rocket from the aircraft. The armament datum line is the longitudinal reference line fixed relative to the aircraft by boresight fittings provided for that purpose. In most systems, means are provided to compensate for any angular difference in the launcher line and armament datum line.

The rocket's actual line of departure is a compromise between directional forces. One is the rocket's own motion, weak at first, along the launcher line. The other is the aircraft's motion along its line of flight, a strong force also imparted to the rocket. The actual direction taken by the rocket is the resultant vector of these two forces, known as the effective launcher line (fig. 5-12).

The aircraft's attitude along the line of flight, its angle of attack, is particularly significant in aiming rockets. It influences the position of the effective launching line and the angle between the zero line of sight and the effective launcher line. The three types of attitudes are as follows:

1. Zero angle of attack
2. Noseup or positive angle of attack
3. Nosedown or negative angle of attack

The effective angle of departure of a rocket is also going to be influenced by the effect of the angle of dive. The steeper the dive, the less the vertical pull of gravity affects the rocket's trajectory and the smaller the aiming allowance for vertical drop. When the effective launcher line points straight down, the force of gravity simply adds to the impetus of the rocket along this line. As the effective launcher line moves toward the horizontal, the more gravity deflects the rocket from its initial path, and the larger the sight angle required.

Rockets tend to follow the direction of flight of the aircraft, while aircraft gun projectiles travel in the direction of aim. The aircraft gun projectile travels close to its direction of aim because the muzzle velocity is so much greater than the speed of the aircraft that the effect of the latter upon the motion of the projectile is slight. The fins of a rocket, on the other hand, tend to align the rocket with the airflow. Since the launching speed is small compared to the speed of the aircraft, the rocket is quickly aligned with the resultant airflow; that is, almost completely in the direction of the line of flight of the aircraft.

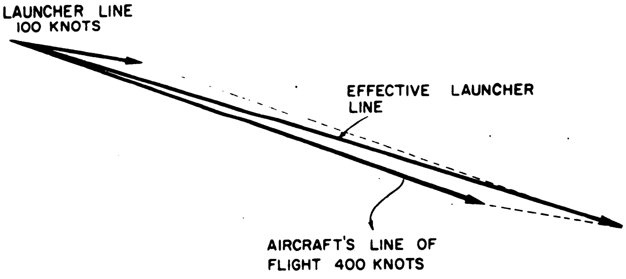

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Figure 5-12.—Effect of launching line.

The rocket trajectory is characterized by considerable curvature compared to the relatively flat trajectory of an aircraft gun projectile. Not only does the longer time of flight lead to a greater gravity drop but, in addition, as the rocket falls, the fins tend to align it along the trajectory, so that there is also a component of the jet force downward, contributing to the normal gravity drop. The consequent large curvature means that the sighting allowance required in aiming and its variation with dive angle are much greater for rockets than for aircraft guns.

Missiles, such as Sparrow and Sidewinder, are provided with a guidance system, and small errors in aiming can be corrected during flight to the target. The missile is actually a pilotless aircraft, and its flight is governed by the rules of aerodynamics. Although some of the factors which determine the trajectory of the gun projectile, rocket, or bomb also affect the missile, the flight characteristics of the missile must be included in determining its trajectory.

SELF-PROPELLING FORCES OF ROCKETS AND MISSILES

As you probably have surmised, the problem of firing rockets from an aircraft is considerably more complicated than that of firing guns. These complications stem mainly from the ballistics of the rocket and the method of launching. These two factors are not easily separated since the trajectory of the rocket depends upon the manner in which it is launched, as well as other factors. One of the main influences on the trajectory of the rocket is the fact that it is self-propelled.

As stated previously, the gun projectile is hurled forward by the pressure of gases expanding in the firing chamber. It has top speed when it leaves the muzzle. A rocket, which is propelled by a jet force of gases produced by burning the propellent charge it carries, starts rather slowly. Because a rocket starts slowly, has a long flight time, and tends to turn downward due to fin and the jet effects, it has a very curved trajectory.

Unlike a gun, even the largest rocket exerts no recoil on its launcher. The back pressure is absorbed in the open air. The only purpose of the launcher is to hold the rocket in place and point it in a given direction until fired. Because of the "no recoil" feature, an aircraft can fire as large or as many rockets as it can carry. A fighter aircraft's salvo of rockets can be equivalent to a destroyer's salvo power.

It is worthwhile to note the differences, related to the methods of propulsion, in the trajectory of rockets and aircraft gun projectiles. These differences are in the following:

1. The velocities
2. The direction of flight
3. The trajectory curvature

Rockets are slower. The velocity of the fastest rocket used at present in forward firing is considerably less than that of an aircraft gun projectile. Furthermore, it takes the rocket a relatively long time to reach its maximum velocity, whereas the aircraft gun projectile has its maximum velocity as it leaves the muzzle. The consequent longer time of flight of the rocket to a given range means that allowances for target speed and wind are much greater than in the case of aircraft gunfire.

METHODS OF INSERTING BALLISTIC INFORMATION

Various weapons systems are provided with different means of inserting ballistic information into the computation when computing for the proper lead. In some systems a separate plug-in unit is designed for each of the different types of armament. Others have this information recorded on the magnetic tracks of a memory drum in the computer. Provisions are made in some systems for manual insertion through a keyboard arrangement, which is an integral part of the system. No matter which method is used, the weapons system will have available all the necessary ballistic information to compute the point-of-aim for any of the different types of armament that the aircraft is designed to carry. These include air-to-air and air-to-ground types.

Although you are not required to determine the factors incorporated, you should be knowledgeable of those that influence the trajectory of a projectile; if for no other reason than to be aware that proper information must be inserted. Also, you should be able to apply the knowledge when taking part in weapon system maintenance-system tests and adjustments.

SOLVING THE PROBLEM

In the preceding section of this chapter, all of the factors presented contributed to the trajectory (movement) of the projectile. Compensating for these factors is fairly simple and in some cases, such as a tail chase or a head-on attack, would produce all the lead angle required to hit the target. However, in many cases involving fast moving aircraft, a head-on or tail chase attack may be undesirable or impossible and some type of deflection shooting is necessary. For deflection shooting, solution of the ballistic lead angle produces only a portion of the total lead angle required.

TOTAL LEAD ANGLE

Just as the duck hunter made allowance for the distance the bird traveled after the weapon was fired, so does a fighter pilot have to make allowance for target motion. This allowance is in addition to the ballistic lead allowed, and is called kinematic lead angle. This lead angle is required because in deflection shooting the line of sight must be turned continuously to keep it on the target.

Line of sight (LOS) can be described as the direction along which the pilot (or tracking radar antenna) of the attacking aircraft looks at any instant when observing the target, as illustrated in figure 5-13. A second line is indicated as the gun line. The angle formed between these two lines is known as kinematic lead and is required whenever the line of sight must turn to remain on the target.

The total lead angle then is the combination of ballistic lead and kinematic lead. The word kinematic is a term used to describe the science that treats motions when considered in themselves. Concern in this course is not with the science itself, but with some of the ideas which have been developed in the science. As can be seen, accurate measurement of the total lead angle is an

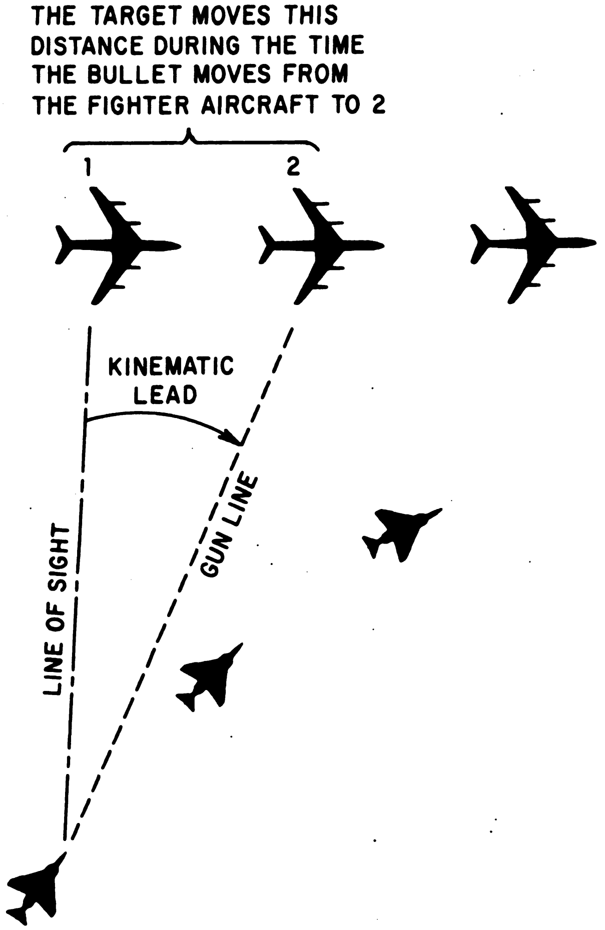
THE TARGET MOVES THIS DISTANCE DURING THE TIME THE BULLET MOVES FROM THE FIGHTER AIRCRAFT TO 2
1
2
KINEMATIC LEAD
GUN LINE
LINE OF SIGHT

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Figure 5-13.—Kinematic lead angle.

absolute necessity. This is done by the use of what is termed the mil measurement.

The standard unit of deflection used in naval aviation weaponry is the bombing mil. The bombing mil is established as an arc, the length of which is 1/1000 of its radius. The radius represents range or bombing altitude, while the length of the arc represents the difference between where the projectile is pointed at launch and its actual point of impact (fig. 5-14). Thus, a 1-mil angle means that at a 1,000-foot range the point of impact would be 1 foot from the point at which the projectile was pointed when launched.

Lead angle of deflection is usually computed in mils. A lead angle of 10 mils for a target range of 1,000 feet results in a difference of 10 feet (at the target) between the line of sight and the centerline of the launcher or gun bore.

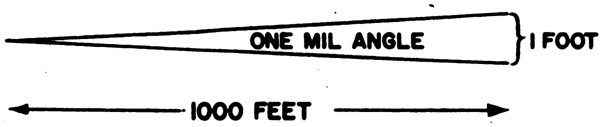

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Figure 5-14.—Diagram of the bombing mil angle.

PURSUIT AND COLLISION CURVES

The problem of determining pursuit curves has a long historical background. The military aspects of the problem were brought into prominence in connection with aerial combat wherein one aircraft is attacked by another possessing guns capable of being fired in a fixed direction only. In order for the one aircraft to keep the other under continuous fire, it must fly some kind of a pursuit course. The problem appears again with the invention of homing missiles which continuously change heading under radio, optical, or infrared guidance.

In general, a fixed weapon fighter flies one of two courses when attacking a target. These are the pursuit course and the collision course. A pursuit course (fig. 5-15) is flown when the

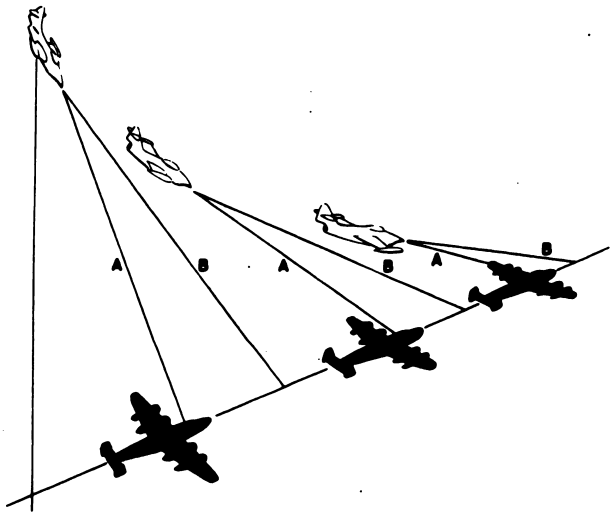

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Figure 5-15.—Typical pursuit course.

firing aircraft maneuvers in a manner to be in a position to fire upon the target continuously throughout the run. In order to produce hits, the fighter is constantly pointing ahead of the target by the correct lead angle, and a projectile fired at any time (within range) can be expected to score a hit. In the process of tracking the target, the pilot must fly a curved path, the curvature depending upon the range, relative target speed, angle of approach to the target, and aircraft's angle of attack.

On this type of course, the weapons are within range of the target and are tracking it for several seconds; consequently, many rounds of ammunition may be fired. Therefore, the pursuit course is used when employing multiple projectiles, such as in aircraft gunfire.

If a pursuit course were carried through, the fighter would eventually be in a tail chase.

The collison course (fig. 5-16) is a straight-line course in space (assuming target velocity to be constant) that positions the fighter so that its projectiles, fired at one point on such a line, will score a hit. There is only one point on such a line where firing is effective. Therefore, the collision course is used when a single salvo of projectiles, such as rockets or guided missiles, is employed. These usually discharge a large amount of ammunition almost instantaneously, thereby increasing the prospects of a kill.

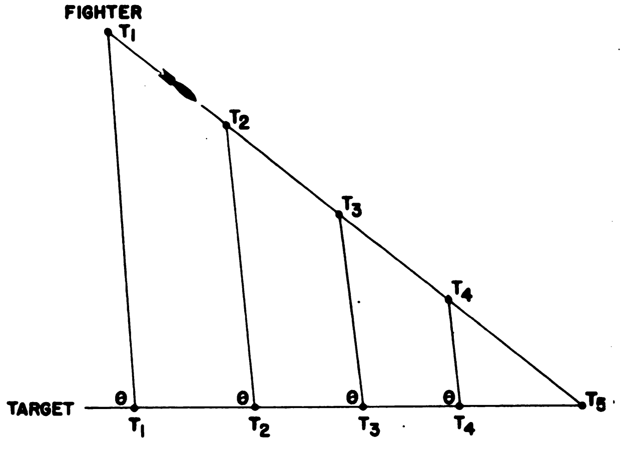

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Figure 5-16.—Collision course.

The pursuing aircraft flies on a prescribed course at a prescribed speed. These are determined by the computers after the target is tracked. At the proper time (T_1), the missile is automatically released. The missile flies in a collision course with the target, bearing a constant angle from the target at all instants of time (T_2, T_3, T_4). Finally, at time T_5 it strikes the target, assuming that the missile maintains a constant velocity.

The chief advantage of the collision course is that the fighter flies a straight-line flightpath. This enables the fighter to reach the firing point faster and break away from the area of defensive fire sooner and with less maneuvering. Note that at the moment of firing from a lead collision course, the fighter is at one position of a pursuit course and could transfer to a pursuit course.

As previously mentioned, one of the elements in the solution of the fire control problem is the effect of the relative motion between the aircraft and its target. Two of the main considerations in determining the effect of this relative motion are the change in distance and the change in angle. This section is concerned with an examination of the rate of change in distance (range) or linear velocity and acceleration.

While the idea of range is generally well known, the concept of rate of change of range does not enjoy such familiarity. As a method of analysis, the two terms are first defined.

Rate is the amount or degree measured in proportion to something (in this case, time), while range is the distance between the aircraft and its target. A combination of these two definitions must result in range rate being the change in distance as measured in proportion to time.

Linear Velocity

Although often freely interchanged, the words speeds and velocity do not have the same meaning. Speed is a reference to the distance covered in a unit of time and is a scalar quantity. Velocity involves both speed and direction, and is a vector quantity. Velocity, then, is the time rate of change of position.

If an aircraft is flying east at 300 miles per hour (mph), its speed would be 300 mph. The velocity of the aircraft would be 300 mph east. Because velocity is a vector quantity with magnitude and direction, there is more than one way to change velocity. The speed can be changed, the direction can be changed, or both can be changed. (See fig. 5-17.)

Velocity is uniform only when equal distances along a straight line are traveled in equal intervals of time. Symbolically, if d is the distance covered in time t, the velocity is:

$$v = \frac{d}{t}$$

How long does it take an aircraft traveling at 200 mph to travel 300 miles?

$$t = \frac{300 \text{ mi}}{200 \text{ mph}} = \frac{3}{2} \text{ hr} = 1 \text{ hr } 30 \text{ min}$$

Remember that both speed and direction are involved in velocity. When one substitutes in the velocity equation, however, only magnitude of velocity is used.

Relative Velocity

In discussing velocity, you must have a point of reference. If two aircraft are traveling with the same velocity (300 mph north) and are separated by 5 miles of distance, they obviously will never make contact. But consider a situation where one aircraft is flying north at 300 mph and the other in front is flying north at 200 mph. The faster of the two will overcome the slower with a rate of change of range of 100 mph. Now consider one aircraft flying south at 300 mph and another flying north at 300 mph. What is the relative velocity between the two or the rate of change of range? ANSWER: 600 mph

If the aircraft flying north were taken as the point of reference, then the other aircraft would have a relative velocity of 600 mph south. In discussions on the fire control problem, the aircraft is often considered as a gun platform. If such is the case, then the velocity of target would always be relative to the gun platform.

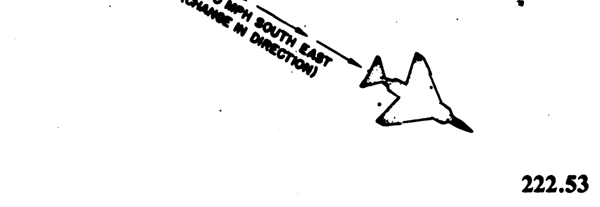

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Figure 5-17.—Change in velocity.

Acceleration

When the velocity of a moving body increases continuously as the motion proceeds, the body is said to move with accelerated motion or to have an acceleration. For example, suppose that the velocity of an automobile increases steadily from 30 mph to 60 mph in 3 minutes. During each minute of the 3-minute interval, the velocity increases by 10 mph per minute. Therefore, the velocity increases at the rate of 10 mph per minute. This rate of change of velocity with respect to time is called constant acceleration. Acceleration may be either positive or negative; positive acceleration meaning an increase in velocity, and negative acceleration meaning a decrease in velocity. Negative acceleration is also called deceleration or retardation.

The equation for average acceleration is:

$$a = \frac{V_2 - V_1}{t}$$

where a is acceleration, V_1 starting velocity, V_2 final velocity, and t elapsed time. The above equation is true only for uniform changes in velocity.

One of the most common examples of motion with a nearly constant acceleration is that of a body falling toward the earth. In a vacuum, all bodies, regardless of their size or weight, fall with the same acceleration (32 feet per second per second near the earth's surface). Because of its effect on a projectile in flight, the force of gravity must be taken into account in the resolution of the fire control problem.

Angular Velocity

The concepts of velocity and acceleration that have been presented so far have dealt solely with linear motion. As we have already indicated, relative motion is composed of both linear motion and angular or rotational motion. The ideas of linear velocity and acceleration presented in the preceding section have their exact parallels in rotational motion. In both cases, displacement with respect to elapsed time is known as velocity, and a change in velocity with respect to time is known as acceleration.

Although the equation of angular motion takes on a simpler form when the angular velocity is expressed in radians per second, the expressions revolutions per second (rps) or revolutions per minute (rpm) are also commonly encountered. There are 2π radians in one revolution. The number of radians per second, therefore, equals 2π times the number of revolutions per second or $2\pi/60$ times the number of revolutions per minute.

The number of revolutions per second is usually referred to as the frequency. The quantity angular velocity $2\pi f$ is represented by the symbol ω(omega). Therefore,.

$$\omega = 2\pi f$$

There are two common methods for measuring angular velocity. In the first method, a revolution counter is held against the end of a rotating shaft and the number of revolutions during a time interval is noted. The time and the displacement are thus measured, and the ratio gives the angular velocity. In the second method, the angular velocity is measured directly by a tachometer. Most tachometers, however, are calibrated in revolutions per minute rather than in radians per second. The common automobile speedometer is a good example of a tachometer calibrated in miles per hour.

The preceding section on linear motion shows that when a body is moving with constant velocity, the distance covered in any period of time is the velocity multiplied by the time. An exact analogy occurs in circular motion. Let Θ (theta) be the angle or the angular distance covered. Then the equation for the angular distance or degrees through which the body rotates is

$$\Theta = 2\pi ft = \omega t$$

where Θ is the total angular distance covered expressed in degrees, revolutions, or radians; $2\pi f$ or ω is the angular velocity in degrees, revolutions, or radians per second; and t is the elapsed time in seconds.

Angular Acceleration

Newton's first law of motion states that "every body continues in a state of rest or of motion in a straight line unless compelled by external force to change that state." Thus, a body is accelerated when a continuous external force is applied to the body either at rest or in uniform motion. If the direction of the external force is in line with the motion of the body and in the same direction, the body is speeded up (accelerated). If the direction of the external force is in line with the motion of the body and in the opposite direction, the body is slowed down (decelerated). If any component of the external force is not in line with the motion of the body, the body is turned from its path.

Most individuals have at some time performed the experiment of tying a weight to a cord and whirling it in a circle. While the object is revolving, there is a pull exerted on the individual's hand. Conversely, the individual's hand must exert an inward pull on the object. This pull of an object whirled around in a fixed circle is due to radial acceleration, as it is called in physics.

If the weight starts from rest and in t seconds acquires an angular speed of ω radians per second, assuming that the process has been done at a uniform rate, it can be said that the angular acceleration α (alpha) expressed in radians per second is

$$\alpha = \frac{\omega}{t}$$

NOTE: This is angular acceleration and not the acceleration of the weight around the circumference of the circle.

In accordance with Newton's second law, a force must be exerted on a moving object to make it follow a curved path instead of a straight path. The necessary force is proportional to rate of change of momentum produced. This force is in the same direction as radial acceleration, which is inward. It is called centripetal force. The name "centripetal" literally means center-seeking. It is the pull which the individual's hand must exert on the string. The opposite or reaction force to this is centrifugal force which means center-fleeing.

Recall that velocity is a vector and that a vector has magnitude and direction. If a body moves at a constant speed around the circumference of a circle, its velocity (v) is always varying because the direction of the velocity is changing. As stated previously, it can be shown that acceleration is toward the center and that the centripetal acceleration (a) is equal to v^2/r, where v is the velocity tangent to the circumference and r is the radius of the circle.

Newton's second law of motion states that force is the product of mass and acceleration or, in equation form

$$F = ma$$

By substituting V^2/r for "a" in Newton's second law equation, it becomes:

$$F = \frac{mv^2}{r}$$

This equation is given to point out the factors influencing the centrifugal force. Recall that centrifugal force is opposite and equal to centripetal force. Notice that the force of centrifugal action increases directly with the mass and as the square of the velocity. Thus, an increase in velocity of three times produces nine times the centrifugal force.

In aviation, the acceleration produced when an aircraft pulls out of a dive is an extremely important factor. Electronic equipment must be designed to withstand the physical strain of centrifugal force in aircraft and guided missiles. The peak acceleration due to a quick turn or pullout is measured by an accelerometer and is indicated in g's. A 10-g pullout from a dive, therefore, means that the acceleration is 10 times that caused by gravity; thus, a 5-pound weight would pull with a force of 50 pounds in a 10-g dive. Electronic equipment for use in guided missiles must not produce distortion when accelerated up to 40 g's.

Further application of centrifugal force is found in the gyroscope. The gyroscope is the basic element in such instruments as the gyrocompass, the gyropilot for aircraft and ships, and certain types of weapons systems.

RELATIVE MOTION

The actual path in space traced by an aircraft as viewed by an imaginary observer at some fixed point in space is, in general, a very different appearing curve when viewed from another aircraft. In figure 5-18, let the horizontal curve (right to left) represent the path of a target aircraft as viewed by the spatial observer. The vertical curve (bottom to top) represents that path of fighter aircraft or airborne gun platform. The t numbers on both curves represent corresponding intervals of time. The distance or range at each interval of time is represented by r. The angle τ (tau) measured from the gun platform to the gun-target line, is called the angle-off of the target or simply angle-off.

The path of the target as viewed by the observer is called the "air course," while the path of the target as viewed from the gun platform is spoken of as the "relative course." Figure 5-18 shows the air course of both target and gun platform. These curves represent the actual motion in space. Notice as time progresses, the range becomes smaller, and the angle decreases and then changes from right horizontal to left horizontal.

In the solution of the air-to-air fire control problem the actual course of either target or gun platform is of much less importance than the relative course. The reason for this is that the correct lead angle for obtaining a hit depends upon the relative motion between the two aircraft.

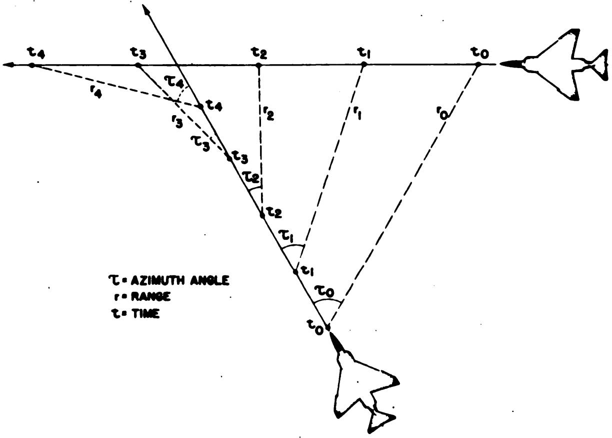

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Figure 5-18.—Air course of target aircraft.

Because the relative course is the important course, consider the path of the target relative to the gun platform. This path may be determined by using a gun platform as reference and measuring the range angle-off of the target for several points. A smooth curve is then drawn through these points as shown in figure 5-19.

In figure 5-19, r_o distance is the same as the r_o distance in figure 5-18, as are all corresponding distances. Angle r_o in figure 5-18 is the same as the angle formed between the flight line and the line from the reference to r_o in figure 5-19. The only difference between the two figures is the reference point. The actual path in space traced by an aircraft as viewed by an imaginary observer at some fixed point in space is, in general, a very different appearing curve when viewed from another aircraft. Figure 5-20 shows both the air and relative courses of a fighter pursuing a bomber.

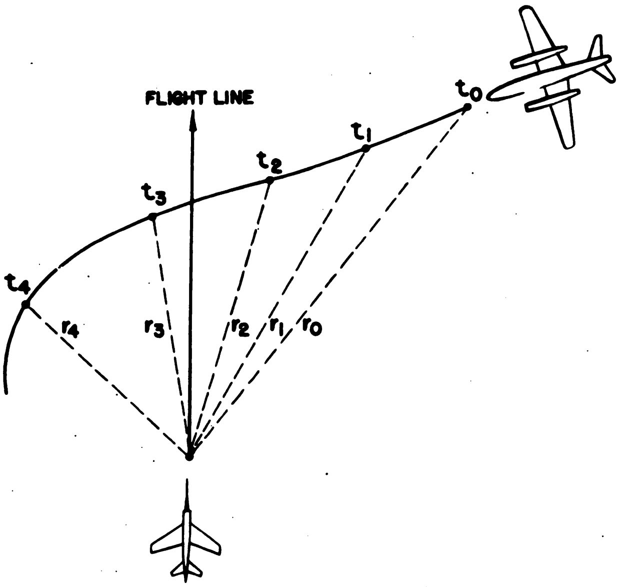

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Figure 5-19.—Relative course of target aircraft.

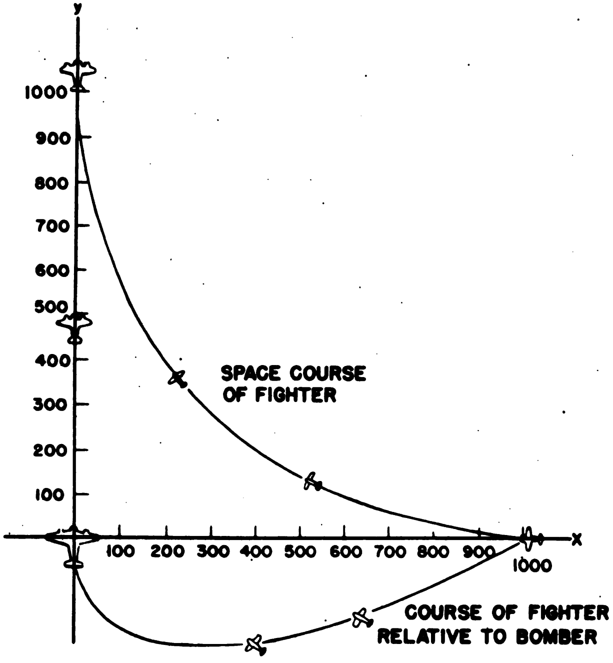

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Figure 5-20.—Air and relative courses of fighter pursuing a bomber.

FUTURE TARGET POSITION

The ability to determine the future position of the target when the projectile strikes is in essence the solution to the problem. There are many factors which contribute to the determination of this future position. To facilitate understanding this problem, consider the following three general cases.

First consider the hypothetical case of a ballistically perfect stationary gun firing at a stationary target in a vacuum and where the projectile is not subject to the effect of gravity. The problem in this case is to aim the gun so that the axis of its bore intersects the target. Since there is no force acting on the projectile except that which expelled it from the gun, it travels along a straight line and hits the target.

In any actual case, such as firing at a stationary target on a target range, the effects of gravity and sometimes of wind are exerted on the projectile and cause it to depart from its straight-line flight. Gravity causes the projectile to travel along a parabolic trajectory. To compensate for its effect, the point of aim must be slightly above the target. Military rifles have this gravity compensating feature built into them in the form of an adjustable sight that allows the rear sight peephole to be raised as the firing distance increases. When the target is aligned with the front and rear sights, the axis of the gun barrel is inclined sufficiently above the horizontal to compensate for the effect of gravity.

The effect of wind on the projectile is apparent, especially when firing at a distant target, but counteracting it becomes even more complicated when one realizes that the projectile travels at a continuously decreasing velocity due to air resistance. Obviously, the slower a projectile travels, the greater the effect of the wind in deflecting it from its course. Nevertheless, in the stationary firing problem, the amount of deflection produced by the wind can be determined after firing a few rounds by observing how far from the bull's-eye the projectiles tend to hit. Aiming the rifle this amount of deflection in an equal and opposite direction from the bull's-eye, results in compensating for the effect of wind.

The problem in the stationary gun and stationary target situation is very simple, and the angle at which one must aim the gun in order to hit the target is easily determined.

In the case of a stationary gun platform and moving target, the situation becomes more complicated. In addition to the effects of wind and gravity, one must foretell where the target will be when the projectile arrives to hit it—the future target position.

Here, as in duck shooting, it is necessary to "lead" the target. The aim must be ahead of the duck by an angle corresponding to the distance the bird is expected to fly between the instant of firing and the time it takes the shot to travel the distance between the gun and the bird. This idea may also be expressed by: "The present position data are used to estimate the future position of the target based upon the rates of change of present position data." In duck shooting, as the bird flies at a relatively slow speed compared to the speed of the shot, the determination of the necessary lead angle is not too difficult and is easily estimated after some experience.

This case is essentially the problem of antiaircraft fire, but also applies to the fighter pilot's problem of correctly aiming forward-firing guns. The basic aiming allowance here is for the arget's relative motion during the projectile's time n flight (kinematic lead). As we have established, additional slight modifications of the gun bore's position must also be made to allow for gravity drop (ballistic lead).

This case is also similar to the problem of precision bombing or aircraft strafing. In these situations, negative leads are required, and the problem is actually "gun platform moving and target stationary." Although similar, there is an important physical difference. In the strafing problem, the velocity of the gun platform is added to the muzzle velocity to obtain the initial velocity of the projectile. The projectile velocity is important in determining time of flight, and time of flight is one of the determining factors in establishing the point of aim. Therefore, there is a slightly different method of solution of the antiaircraft problem and the strafing problem. In the air-to-air problem the initial velocity of the projectile is established as in the strafing problem.

In the case of air-to-air gunnery where two aircraft are traveling at near sonic speed and where their relative velocity begins to approach the order of the velocity of the projectiles themselves, the problem becomes much more difficult. The necessary lead angle can no longer be mentally estimated as in the case of the duck hunter, but must be continuously and accurately computed.

While this is the most complex of three general cases, it is very similar to the preceding case of gun stationary and target moving. This case is generally solved by the angular rate of travel prediction for high speed; and for lower speed involving surface ships and submarines, linear speed prediction is utilized. In aviation fire control, the angular rate of travel prediction is the method used.

AIR-TO-AIR LEAD ANGLE PREDICTIONS

By use of the concept of relative motion, and by considering the gun stationary and the target moving about it, the air-to-air problem can be resolved to the stationary gun platform and moving target case. Using the angular rate prediction method, two lead angles are material in considering the problem of a projectile leaving a moving fighter aircraft and striking a moving target. These are the lead angles necessary to compensate for the effects of the relative motion between the aircraft gun and the target (kinematic), and to compensate for the ballistic effects on the projectile during its flight.

While there are many factors that go into its determination, the lead angle necessary at any instant of time may essentially be considered equal to the product of the angular velocity of the target with respect to the firing aircraft and the time of flight of the projectile. A discussion of the main factors and their effects contributing to this determination of the lead angle follows.

Range

Range may be divided into two categories, present range (r) and future range (r_f). As pointed out in the previous section, present range may be determined optically or by radar. Future range is the distance from the weapon at the time of firing to the point of impact of the projectile. Future range is one of the factors that must be computed in the solution of the fire control problem.

Time of Flight

Time of flight (t_f) is the time taken for the projectile to cover the range from the firing point to the future position. If the present range is the target's position at the time of firing, then the time of flight is the time for the projectile to travel the distance of the future range. But, the computation of future range is dependent upon a knowledge of the time of flight. Hence, it is seen that time of flight and future range are interdependent on one another. The future angular position of the target is also dependent on the time it takes for the projectile to reach the target.

If the projectile were fired at a target in a perfect vacuum, and if the projectile were not subject to deflection by ballistics factors, it would move along a straight line at a constant velocity. For such a hypothetical situation:

$$\text{Time of flight } (t_f) = \frac{\text{Range}}{\text{Muzzle velocity}} = \frac{r_f}{V_o}$$

In practice, however, the influence of gravity causes the projectile to move along a parabolic trajectory and the actual distance it travels must of necessity be greater than the straightline distance r_f. Since the projectile is traveling through air, it is decelerated by the air resistance. The amount of deceleration is determined by the air density and size and shape or contour of the projectile. Another factor affecting time of flight is the true airspeed of the aircraft which must effectively be added to the gun's muzzle velocity to determine the deceleration caused by air resistance. From these factors the average velocity of the projectile, referring to the straight-line distance r_f, must be computed to obtain time of flight. In practice the empirical equation for the time of flight becomes:

$$\text{Time of flight} = \frac{\text{Range}}{\text{Muzzle Velocity}} + \text{Lost time of flight}$$

or:

$$t_f = \frac{r_f}{V_o} + t_L$$

Relative Velocity of Target

The relative velocity of the target may be broken down into two components, range rate and angular rate. Range rate, as shown previously, is the rate of change of range in respect to time. If a radar is used for ranging, the range rate may readily be determined by electronic means. Because the gun platform is used as reference, the range rate is the relative rate of change between target and gun. When the range rate is multiplied by the time of flight, the product is the total change in range by the time the projectile hits the target. Adding this product to the present range results in the future range of the target at the time when the projectile hits the target.

The angular velocity of the target with respect to the firing aircraft means the rate at which the line joining the target and the firing aircraft is turning or rotating, assuming the firing aircraft to be still. Thus, if the relative angular velocity is 5° per second at any particular instant of time and the time of flight of the projectile to the predicted target position is 1/2 second at that same instant, the necessary lead angle at that instant will be 2 1/2°.

Because of the three dimensions involved in the air-to-air fire control problem, angular velocity or angular rate is at times divided into two components. These are azimuth angular velocity and elevation angular velocity.

In the optical fire control equipment, the angular velocity of the target is determined during the tracking phase when the pilot flies a coordinated turn. In such a turn, the gyroscope of the sight unit is offset from its zero position by the aircraft's angular velocity in space. This offset is the result of the inherent rigidity of a gyroscope. There is only one gyroscope, but because of the method of sight construction the gyroscope determines both azimuth and elevation portions of angular velocity.

In the radar director system, measurement of angular velocity is accomplished by means of two rate gyroscopes located in the antenna assembly. The azimuth-rate gyro precesses whenever the azimuth component of the antenna angle changes, while the elevation-rate gyro precesses only when the elevation component of the antenna angle changes. The degree of precession of these rate gyros is proportional to the rate at which these angular components are changing.

Present Lead Angle

The present lead angle is the angle at any instant of time. The present lead angle is compared with the lead angle furnished by the computer to determine whether or not the gun platform is pointed in the right direction. The present lead angle may also consist of two components, the azimuth and elevation portions.

KINEMATICS GRAPHICALLY RESOLVED

As an example of the graphical resolution of the kinematic lead angle, first consider the case of a fighter flying a lead pursuit course towards a target when both target and attacking aircraft are in a single horizontal plane; that is, both at the same altitude. The conclusion drawn from this case is then generalized in three dimensions. A typical lead pursuit attack in a horizontal plane is illustrated in figure 5-21.

Two Dimensions

In figure 5-21, the fighter is at a present position G, the target is at present position T, and the present range between the two aircraft is r. It is assumed that the fighter is on a lead pursuit curve; that is, a projectile fired at (this) present time would arrive at the future position of the target, T_f, with the target and would score a hit. The kinematic lead angle is denoted by using the Greek letter lambda (Λk).

As shown in figure 5-21, the fighter will be turning at the time of firing. However, such fighter motion will have no effect on the flight of the projectile. Only the direction and speed of the fighter at the time of firing affect the flight of the projectile. So far as the projectile is concerned, it is assumed that the fighter continues to fly in the same direction as at the time of firing, although in reality this is not true. The actual position of the fighter when the projectile hits the target will be G_f. For the purpose of calculation, it is assumed that the future position of the fighter is G'_f which lies on the flightpath of the projectile.

Referring once again to figure 5-21, the target flies from T to T_f while the projectile travels from G to T_f and the fighter is assumed to fly from G to G_f. The time of flight of the projectile is denoted by t_f. (Be careful not to confuse this with T_f—target future position.) Therefore, the target flies a distance equal to its velocity multiplied by the flight time of the projectile or $V_T t_f$. The fighter flies a distance equal to its velocity multiplied by the flight time of the

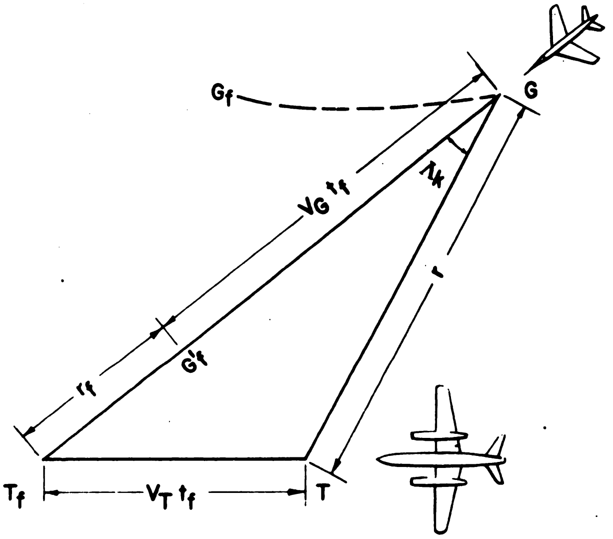

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Figure 5-21.—Lead pursuit course in horizontal plane.

projectile or $V_G t_f$. The distance between the fighter and the target when the projectile hits the target is called the future range r_f. This is also the distance or range the projectile would attain in front of the fighter during its time of flight.

Consider the relative motion of the target in respect to the fighter. The relative course is a straight-line course at a constant speed. The initial range is r, and t_f seconds later the range will be r_f. Figure 5-22 shows this relative course.

In figure 5-22, the relative position of the fighter remains fixed at G throughout the course. The present position of the target is T. Thus, the present distance to the target is r and is represented by the line GT. The target appears to fly in a straight line (at constant speed, V_T) towards position T_f, which is the relative position of the target t_f seconds after the present time. The relative distance it flies is $V_T t_f$. The future position of the target T_f is at range r_f from the fighter which is represented by the line GT_f. Therefore, the present kinematic lead angle, Λ, is the angle between the line of sight and the line of flight of the fighter.

Three-Dimensional Case

Now consider the three-dimensional case. In this case the fighter and target may be climbing or diving, but it is still assumed that the target is flying a straight line, constant speed course. The three-dimensional situation of a fighter attacking a target is shown in figure 5-23. The target flies horizontally from T to T_f (fig. 5-23) while the fighter is diving on the target. Notice that the target's course is intersected at T_f by the extension of the fighter course.

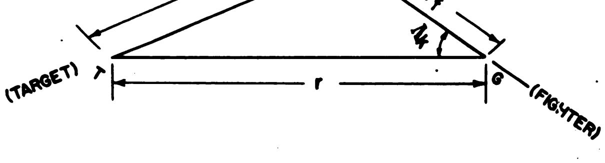

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Figure 5-22.—Relative motion of target to fighter on pursuit course.

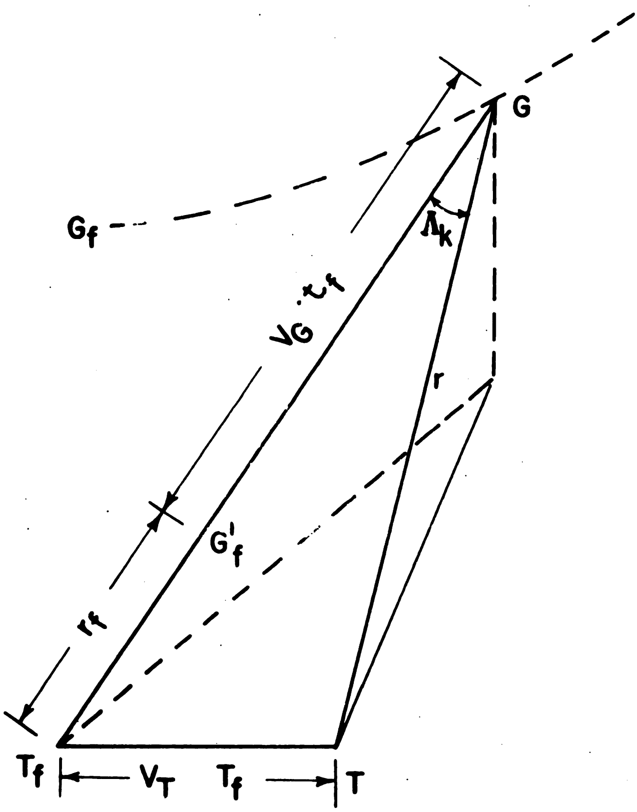

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Figure 5-23.—Three-dimensional view of pursuit course.

This problem differs from the preceding two-dimensional case in that the determination of the kinematic lead angle is dependent upon two factors, the azimuth component, ΛkA, and the elevation component, ΛkE. As in the single plane case, the lead angle is dependent upon angular velocity. When using the radar system for computing the lead, the angular velocity of the target is determined by rate gyroscopes positioned on the antenna. In the optical system, airstream direction detectors are used for measuring the angle of attack and the angle of skid. In both systems the information concerning both the elevation and azimuth angles is fed to a computer where the other factors are added. The result is computation of a correct lead angle resulting in the projectiles arriving at T_f at the same instant as the target.

The preceding discussion of the kinematic lead angles (lead angles due to the relative motion of the attacking aircraft and the target) was developed under the assumption that the flightpath of the projectile is a straight line in space. This neglects the effects of the ballistics factors. The ballistics lead angles are generally much smaller than the kinematic lead angles, but must be taken into account.

WEAPONS SYSTEMS CONCEPT

In the relatively recent past when a weapons system was mentioned, it was in reference to a fairly unsophisticated special purpose system. The components that made up the system, when installed in the aircraft, were independent of any of the other systems in the aircraft. At the time they were not very complicated, since aircraft speeds were quite low and targets were attacked at comparatively short ranges. The accuracy of the system was dependent to a great extent on the operator. This arrangement was true of nearly all of the many systems required to perform the aircraft's mission. As aircraft altitudes increased and speeds reached the supersonic regions, the ability of the attacking aircraft to perform its mission became more difficult. To engage a target at supersonic speeds was impossible when depending only on the operator for accuracy. To solve these problems automatically and accurately, the equipment became very complex.

The result of all this was that current aircraft are designed and built as a completely integrated machine. Each of the heretofore separate systems are now subsystems which are interconnected and dependent, to some extent, on each of the others. For example, the navigation system is dependent on the radar system; and the automatic flight ontrol system is dependent on a computer, which s dependent on both the radar and navigation ystems for proper operation.

The F-4B is an example of one of the first ircraft to be designed and built as a complete weapons system. Other aircraft that have nce joined the fleet are the A-6, A-7, and -14, which have completely integrated weapons stems.

SUBSYSTEMS

Even though all the systems are interdependent and interconnected, much of the familiar identification nomenclature is still retained. Although reference is made to individual systems, it is becoming increasingly difficult to separate them. You, as an AQ, will normally have a primary responsibility for the aircraft's weapons system.

Fire Control System

In recent type aircraft, the fire control systems are often called intercept systems; and if they have missile capabilities, they are also referred to as missile control systems. Either is used to intercept an airborne target or attack the enemy on the surface. Many of the newer aircraft have multiple capabilities, missiles, bombs, rockets, and guns. Hence the term, weapons system.

There are basically two types of intercept systems, visual and all-weather. Normally both types are provided; each type is used to best advantage by the pilot, bombardier/navigator, or other crewmember, depending on the type of target being attacked. A visual attack could be made on a surface target with good results, whereas perhaps an airborne target would require the all-weather attack since long-range detection is usually required and radar is then employed to lock on and track the target.

SYSTEM COMPONENTS

The effective use of any weapon requires that a destructive device (usually containing an explosive) be delivered to a target, usually a moving target. To deliver the weapon accurately, both the velocity and location of the target must be known. Many targets now travel faster than sound and must therefore be engaged at great distances. Against such targets, a weapon is most effective when it is used as part of a weapons system. A weapons system is the combination of a weapon (or multiple weapons) and the equipment used to bring their destructive power against an enemy.

A weapons system includes the following:

1. Units that detect, locate, and identify the target

2. Units that direct or control the delivery unit or the weapon or both

3. Units that deliver or initiate delivery of the weapon to the target

4. Units that destroy the target when in contact with it or near it; these units are usually termed weapons.

Detecting Units

The first steps in using a weapons system and solving the problem are to detect, locate, and identify the target. Initial contact may be visual, or it may be made by radar. It is difficult to detect a target visually at long range, or even at short range, when visibility is poor. For that reason, targets are usually detected by radar. Radar gives all three coordinates necessary to determine the position of the target. These are range, elevation, and azimuth positions.

Optical devices are used to supplement this information on occasions, such as for slow-moving targets or for short ranges. They are practically useless against missiles and most jet aircraft which usually must be engaged while they are still beyond the range of optical devices.

After the target has been detected and located, it must be identified. To do this requires a device called IFF (identification, friend or foe). Radar alone cannot tell the difference between a friendly or enemy target. IFF equipment consists of two major units, the challenging unit which asks the question, friend or foe, and the transponder (responding unit) which answers the question. The challenging unit is a receiver/transmitter that sends out a pulse of radio energy toward the target. If the target is friendly, it will carry a transponder, which also consists of a receiver and a transmitter. When the receiver picks up a challenge, it causes the transmitter to send out an answering pulse or pulses, which is usually a coded message. This message is picked up by the challenging unit's receiver and displayed on a radar indicator.

Control Units

Control units in a weapons system develop, compute, relay, and introduce data into a delivery unit, weapon, or both. They direct, control, or guide the weapon to the target, and cause it to function in the desired manner. These units form the heart of the weapons system.

The devices that perform the control functions include data transmission systems that send target position information developed by the detecting units to the rest of the weapons system. Examples are synchro, resolver, and potentiometer circuits. Computer devices process the input data from the detecting units and other sources, and put out information used in aiming to cause the weapon to reach the target. Reference devices such as stable elements establish reference planes and lines of fire, lines of sight, and other references. These units are usually gyroscopically controlled.

DATA LINK.—Data link provides the capability for pursuit of a target that is beyond the operating range of the radar system. The target is tracked by a remote ground, shipboard, or airborne radar installation. Target flight parameters are compared with the flight parameters of the interceptor at the same instant. This information is analyzed by a computer at the remote installation and the data, along with attack instructions, is transmitted to the interceptor on a digital data communications link. Data link operation makes it possible for the interceptor to approach the target closely without announcing its presence, since it is not necessary for the interceptor radar to be transmitting at this time. Once the target is within the effective operating range of the fire control system, normal radar acquisition and tracking can be resumed. Some fire control systems also employ a digital data communications link between the interceptor and the missile after it has been launched.

Delivery Units

Broadly speaking, delivery units launch o project destructive units toward the target Examples are guns, missile and rocket launchers and so forth.

Destructive Units

The end purpose of the detection units, control units, and delivery units is to cause the destruction unit to intercept or pass near the target. It is then the function of the destruction unit to destroy or inflict maximum damage to the target.

SUMMARY

In this chapter you have been introduced to some of the fundamentals that deal with aircraft weapons control. You are now aware of some of the things that influence the flight of a projectile or a missile after they have been fired or released, such things as lead angle, air density, gravity, and so forth. In no way have we provided a detailed presentation of weapon control fundamentals. However, hopefully, you are more aware of the factors that affect the flight path of a weapon. The following provides a summary of the information presented in this chapter.

PRIMARY PROBLEM—The primary problem of aircraft weapons systems is to accurately determine the correct position and altitude in which to place the aircraft in order to be reasonably sure of making a hit on the target. In almost all cases, this requires the generation of a lead angle.

BALLISTICS—A term which refers to the science of the motion of projectiles. It is a study of all the various forces which govern the movements of projectiles. The study of ballistics is normally divided into two branches, interior and exterior.

GRAVITY—One of the major factors that affect the trajectory of a projectile is gravity. The longer the distance to a target and the slower a projectile, the greater the gravity drop.

AIR DENSITY—A factor which contributes to the resistance offered by the air to the flight of a projectile is air density. Cross sectional area and velocity of the projectile are other factors. The effect of air density is more pronounced in the early part of the trajectory.

TEMPERATURE—Temperature is used in the determination of air density at different altitudes. It is also used in the determination of the true airspeed of an aircraft.

RIFLING—Rifling imparts a spinning motion or rotation to a fired projectile. The spinning stabilizes the projectile in flight, causes it to act as a gyroscope. A rotating projectile during flight is subjected to a force which causes it to drift. Drift is normally to the right.

TRAIL—With a constant airspeed and course, the horizontal distance that a bomb has lagged behind an aircraft at the instant of impact is called trail. The amount of trail is governed by the airspeed of the aircraft at the time of release and the length of time that air resistance acts on the bomb.

WIND—Wind is defined as the motion of air relative to the Earth. It is a consideration for air-to-ground engagements. If a wind were blowing upon a bomb, it would cause it to drift with respect to the ground. Wind blowing upon an aircraft would also affect its performance and would be a consideration, for that reason, in an air-to-ground attack.

ANGLE OF DEPARTURE—The angle that the line of departure makes with the horizontal is the initial angle of inclination of the trajectory and is called the angle of departure. Maximum range is obtained (in a vacuum) at an angle of 45°. Range is considerably decreased in an air trajectory.

PURSUIT AND COLLISION CURVES—In general, a fixed weapon fighter flies one of two courses when attacking a target. These are the pursuit course or the collision course.

RANGE—There are two categories of range, present range (r) and future range (r_f). Present range may be determined optically or by radar. Future range is the distance form the weapon at the time of firing to the point of impact of the projectile. Future range is used in the determination of time of flight (t_f).

$$\text{Time of flight} = \frac{\text{Range}}{\text{Muzzle Velocity}} + \text{Lost time of flight}$$

WEAPONS SYSTEM—A weapons system includes the following:

1. Units that detect, locate, and identify the target
2. Units that direct or control the delivery unit or the weapon or both
3. Units that deliver or initiate delivery of the weapon to the target
4. Units that destroy the target when in contact with it or near it; these units are usually termed weapons.

CHAPTER 6

THE BOMBING PROBLEM

In the last chapter, we touched upon the bombing problem when we discussed the air-to-ground trajectory, the effects of air density and wind on a bomb or an aircraft, and trail and crosstrail. We did not, however, discuss the problem in any great detail. This chapter provides a more detailed discussion of the problem.

As we pointed out in the last chapter, whether a bomb strikes a target depends on the aircraft being in the proper position and attitude in relation to the target at the time of release. Accordingly, weapons-systems furnished information (visual and computed) will assure a hit if the pilot puts the aircraft on the flight path indicated, and if the projectile is dropped or released in accordance with the predetermined ballistic formula.

FACTORS AFFECTING BOMBING

Several types of bombing attacks have been developed, each with particular advantages and disadvantages, and each designed to fit certain needs. In general, determination of the required type of bombing depends on such factors as:

1. Nature of target
2. Nature of ground and air defense
3. Type of damage desired to the target
4. Weather conditions over the target
5. Distance to the target

VACUUM TRAJECTORY

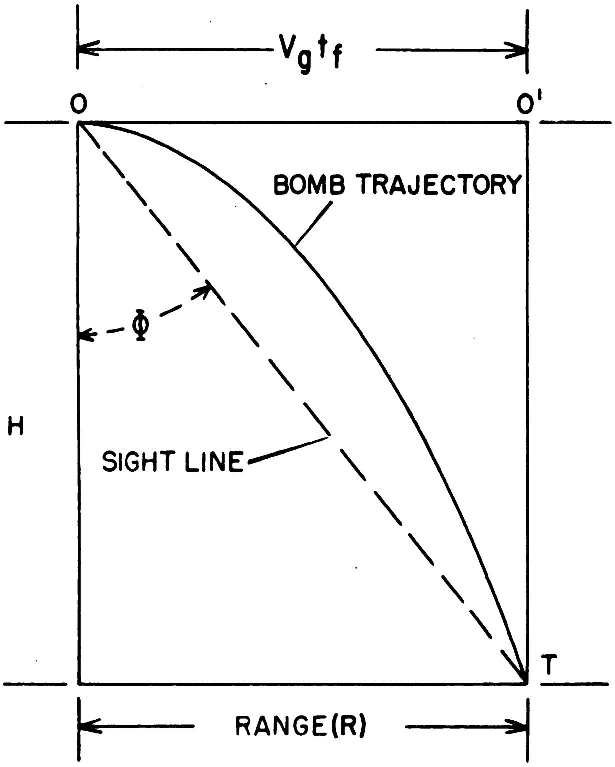

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Figure 6-1.—Bomb trajectory in a vacuum.

In discussing high level bombing, first consider the action of a free-falling body in a vacuum. Refer to figure 6-1. Suppose that the bomber travels the line from 0 to 0′ with a constant speed V_g knots. Suppose also that the bomber requires t_f seconds to cover this distance, that the bomb is released at point 0, and that the bomber is H distance above the target at T. Since no air resistance is presumed to be acting, the horizontal component of the bomb's velocity is the same as the bomber's velocity at all points of its trajectory. Thus it can be seen that during its fall, the bomb will remain vertically below the aircraft.

The space path of the bomb is shown in the figure while its path relative to the bombardier is simply a vertical straight line.

Since the distance traveled horizontally is equal to velocity multiplied by time, the bomb's horizontal travel, or range R, is equal to $V_g t_f$. The angle formed at the time of release between the true vertical and the line of sight is called the range angle. The symbol for the range angle is shown as the Greek letter Φ (phi).

To determine the right angle, three factors are required: aircraft velocity (V_g), altitude (H), and acceleration due to gravity (g). Acceleration due to gravity remains constant. This leaves two variables, H and V_g. The variables can be measured and the range angle Φ computed. Therefore, to hit a target when flying straight and level at a predetermined altitude and speed, it is only necessary, assuming air resistance on the bomb during its fall to be negligible, to drop the bomb as soon as the target appears at the angle Φ from the vertical.

AIR TRAJECTORY—NO WIND CONDITION

Now consider the bombing problem in air, but under no wind conditions. The difference between the two situations is the effects of air resistance which has two important effects on the path of the bomb. First, it decreases the vertical velocity of the bomb, thereby increasing the time of fall. Second, it diminishes the horizontal velocity of the bomb, thus causing the bomb to trail behind the vertical line of the bomber.

The exact effect of air resistance on a particular bomb depends on the type of bomb as well as the release conditions. For example, a small, streamlined bomb is less affected by air resistance than a large, irregularly shaped bomb of equal weight. Consequently, the small bomb falls faster, and its time of fall is less. The effect of air resistance on any bomb is determined by the bomb's "ballistic coefficient." The ballistic coefficient for any bomb type is obtained from tables determined from actual bomb drops. Therefore, in addition to altitude above the target and vertical velocity, the time of fall for a bomb dropped in air is dependent upon the ballistic coefficient.

The effect on range is that the bomb no longer remains beneath the aircraft while falling, and that range no longer equals time of fall (t_f) multiplied by aircraft groundspeed (V_g). The reason is that the air resists the horizontal motion of the bomb, causing a gradual reduction of its horizontal velocity. The effect of the increase in t_f is more than offset by the decrease in the bomb's horizontal velocity. Figure 6-2 shows the effect of air resistance on bomb trajectory and, for comparison, the trajectory of an ideal bomb in a vacuum.

With a constant airspeed and course, the horizontal distance that the bomb has lagged behind the aircraft at the instant of impact is called trail (T '). The amount of trail is governed by the aircraft's airspeed at the time of release. In addition, it is dependent upon the altitude of release and the ballistic coefficient of the bomb. Trail values for each type of bomb are determined during the calibration of the bomb at the proving ground and are set forth in tabular form, trail being given in angular measure (mils). In bombing practice, the value of an angle in bombing mils may be found by dividing the distance on the ground by 1/1000 of the altitude.

Figure 6-2 shows that the range (R) of the bomb dropped in air is obtained by subtracting the linear trail value from the vacuum range. An ideal bomb dropped from point P hits the ground at impact point A. During the time of fall, the aircraft travels distance $V_g t_f$, where t_f is for the ideal bomb. Thus, at impact, the aircraft is directly over point A. An actual bomb dropped

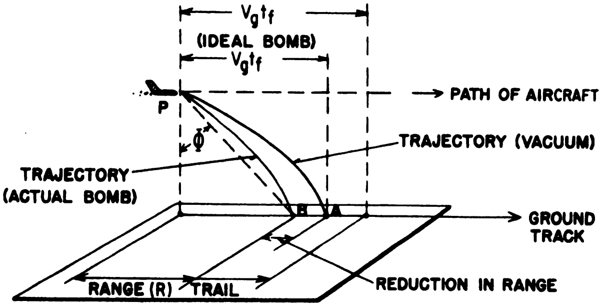

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Figure 6-2.—Effect of air resistance on bomb trajectory.

from point P hits the ground at impact point B because of air resistance. Since t_f for the actual bomb is greater than that for the ideal bomb, the aircraft travels the distance $V_g t_f$ (actual) during the time of fall. Thus, trail includes not only the reduction range, but also the travel of the aircraft during the additional time of fall.

DRIFT AND TARGET MOTION

Up to this point, our discussion of the bombing problem has assumed the conditions of still air and a stationary target. Now consider the problem with the introduction of wind. In a standard air structure, the wind is considered as moving horizontally only, with constant speed and direction at all points of the bomb trajectory. Thus, no vertical component of wind is considered.

As pointed out in the last chapter, the principal effect of either a head wind or a tail wind is the change made in the closing speed of the aircraft. The problem that we want to consider, however, is the one that results from a wind other than a head wind or a tail wind. The geometry of this type of problem is illustrated in figure 6-3.

In figure 6-3, the line AD gives the direction in which the aircraft is being steered; namely, the aircraft's heading. The vector V_a is the velocity of the bomber with respect to the air. The wind vector V_w, representing the velocity of the air with respect to the ground, combines with V_a to give V_c (V_g and V_c are the same when the target is stationary), the velocity of the bomber with respect to the ground. The line AA′ is the line of action of vector V_c and is called the bomber's track. The angle θ (theta), formed by the heading and the track, is called the drift angle. (The Greek letter theta is used here to denote drift angle. In some bombing computers, letters may be used to denote drift angle, while theta denotes the angle between true north and the aircraft centerline.)

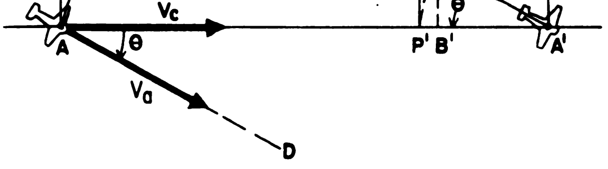

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Figure 6-3.—Drift angle and trail.

There are three important points to be noted in figure 6-3. First of all, the direction of the trail (T′) always lies in a line through the forward-aft line of the aircraft and is independent of the wind. Second, it should be noted that because of this fact the bomber must fly so that its track will pass to one side of the target by the amount P′T to obtain a hit. (NOTE: P′T equals T′ sin θ.) This quantity is called the crosstrail. Third, as figure 6-3 shows, the bomb will strike (unless a special correction is made) not at the target T but at a slight distance forward at B. To account for this, it must be remembered the trail (T′) is independent of wind and therefore θ. Thus, the bomb will strike at T only when θ is at zero. (This is because flight is in still air along 00′.) Therefore, to secure a hit at T, the bomb should be released when the aircraft is the distance TB back from A′ along the track. This factor is called the range component of crosstrail. It is usually very small, being obscured by other bombing errors, and for this reason is sometimes omitted from consideration.

So far, we have given consideration only to stationary targets. In order to take target motion into account, target velocity must be resolved into components along and perpendicular to the aircraft's heading. Then that component of the target's motion along the aircraft's heading gives the same effect as a head wind or a tail wind depending upon whether its direction is the same or the opposite of the aircraft's direction. Similarly, the component of the target's motion across the aircraft's heading may be considered as a crosswind and absorbed in the solution for the drift angle by combining it with the wind vector. Hence, the effect of target motion is merely to change the values of aircraft velocity and wind velocities (V_a and V_w), and then to regard the target stationary as before. The correct range or dropping angle Φ is a function of the trail, altitude above the target, time of flight of the bomb, and the closing speed, V_c.

RELEASE POINT COMPUTATION

The release point problem consists of determining the course to fly and the point along that course at which the bomb must be released to hit the target. Release point computation is based on solution of the tracking and bomb ballistic problems.

Tracking establishes the position and relative motion between the aircraft and the target. Tracking data are obtained by tracking the aim point, which may be either the target or an aim point displaced from the target. A displaced aim point can only be tracked when the target is stationary and the position of the target with respect to the aim point is known. Position data establish the initial position of the aim point with respect to the aircraft, and the rates continuously establish the change in position of the aircraft relative to the aim point.

As noted before, the correct range or dropping angle Φ is a function of the trail, altitude above the target, time of flight of the bomb, and the closing speed. Previous to this, there is the problem of establishing the proper track parallel to a collision course with the target and at a distance equal to the crosstrail.

A bombing computer for determining Φ has as inputs T', H, t_f, and V_c. The trail (T') is obtained from trail tables, wherein it is given as a function of altitude, airspeed, and bomb ballistic coefficient, and can thus be set in by the bombardier. The altitude input is available from an altimeter while time of flight is tabulated as a function of altitude. Closing speed is obtained by tracking the target with the use of optical devices, a television camera, or radar keeping the crosshairs or range and azimuth cursors continuously on the target. This method of computing the release point is similar to the range angle method used when tracking with a bomb sight.

Modern bombing equipment provides stabilization of the sighting unit (radar antenna, TV camera, and so forth) so that references are available from which to measure the range and drift angles. Chapters 4 and 9 of this manual describe stabilization.

METHODS OF DELIVERY

For tactical requirements, a number of general types of bombing have been evolved for Navy use.

These methods of bombing may be divided into the following categories:

1. High level horizontal bombing (altitude 5,000 ft and above)
2. Low level horizontal bombing (low altitude)
3. Toss, loft, and over-the-shoulder bombing (low altitude)
4. Dive bombing

Level bombing consists of the aircraft flying a straight horizontal line during its bombing run.

HIGH LEVEL BOMBING

High level bombing altitudes are considered to extend from approximately 5,000 feet to the ceiling of the aircraft. The greater the altitude, the safer it is from conventional ground fire; but the problem is more difficult and more precise information must be used to solve it. Many factors must be taken into consideration. As we pointed out at the beginning of this chapter, some of these factors are discussed in the preceding chapter. In this chapter, let's carry the discussion a little further.

LOW LEVEL BOMBING

Low level bombing is usually considered to be from 5,000 feet and below. At such altitudes, many complications present themselves that are of lesser consequence in high level bombing. There are also factors encountered in low level bombing that are not a part of the high level bombing problem.

At low altitudes the attacking aircraft may be subjected to severe conventional ground fire. This problem has been partially solved by flying very low to avoid detection; however, extremely low altitude flight presents another very serious problem. This is the problem of avoiding the terrain, which includes mountains in many areas, or other obstructions. The solution was the development of a special terrain clearance radar.

The increasing speeds of modern aircraft have made it impossible to bomb at low altitudes with accuracy when depending on bombsights and the pilot's judgment. Thus, automatic bomb release systems have been developed and are used in modern aircraft. To point out the need for automatic release equipment, two methods previously used in low level bombing are discussed briefly.

A bombsight that operates effectively at altitudes below 5,000 feet requires extreme accuracy in measurement of the input variables when the range angle method is used for determination of the bomb release point. This is especially pronounced when the altitude falls below 1,000 feet, as it does in the case of depth bombing of submarines from low flying aircraft. At such low altitudes, the trail value is negligible by comparison to other factors. Therefore, unless the altitude and closing speed can be held very close to the preassigned values, errors in these quantities produce large range errors. To overcome these difficulties, the angular rate method was used to determine bomb release.

During the early stages of a low level approach, when the target is at a considerable distance from the aircraft, the angle of depression (fig. 6-4) changes very slowly so that the angular velocity of the target at the observer's eye is low. As the aircraft nears the target, the angular velocity increases, finally becoming a maximum as the aircraft passes vertically over the target.

At some point during this bombing run, the target was in an appropriate position for a bomb to be released. At that point it has an angular velocity that could be calculated in terms of the height and groundspeed of the aircraft. If this calculated angular velocity is set up on a bombsight in such a manner that at the exact moment the target has an equal angular velocity, there would be an indication of the exact instant when the bomb should be released. The solution of the low level bomb attack as just described would be impossible with today's high speed aircraft because of the human error factor.

DIVE BOMBING

Dive bombing is accomplished by flying along a dive bomb path as illustrated in figure 6-5. This path provides the proper aiming allowance at the release point to obtain a hit. By following a path as shown, the aircraft is directed at point A beyond the target T, so that when the bomb is released at point R, it will not fall short due to gravity. Hence at release, the line of sight to the target and line of flight are at an angle to each other.

In the development of dive bombing, as the altitude for beginning the pullout increased, the need for equipment to indicate the correct release point increased. The big problem in dive bombing has always been to determine the proper point to aim the aircraft. For any given aircraft speed, aircraft load, and dive angle, the amount of offset that must be allowed above or below the boresight line of the aircraft so that the aircraft will fly a straight path to the target, can readily be determined. However, when released, the bomb will always fall short by an amount which is mathematically a function of height and ballistics of the bomb. Accordingly, the problem

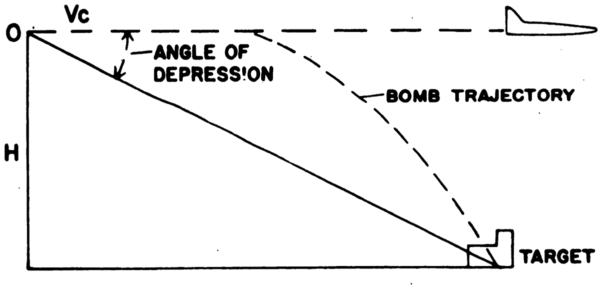

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Figure 6-4.—Low level bombing.

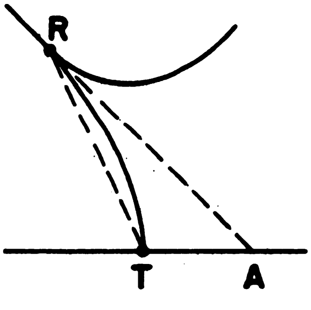

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Figure 6-5.—Dive bombing.

has been solved by diving the aircraft at a constant speed with a known load and dive angle, while aiming the aircraft at the target in accordance to offset corrections determined by the bomb director.

A sight was constructed to operate on the angular rate principle, but after numerous flight tests, was finally rejected for the following reasons. First, it was found too difficult for the pilot to maneuver the aircraft in the diving attitude to achieve synchronization. Actually, the pilot had to fly a curved path through space and at the same time, try to recognize a condition of no drift between the crosshairs and the target. Second, when once in a dive, the pilot found it almost impossible to make a deflection drift correction since there is no way to make an aircraft move sideways in space. The fact that range and deflection drift change continuously creates a problem virtually impossible for the dive bombing pilot to solve.

The difficulties just mentioned have been reduced by new equipment, but cannot be avoided altogether, since they are inherent in the dive bombing method. The method of toss bombing, considered in the next section, eliminates these difficulties for the pilot by permitting a dive straight at the target.

TOSS BOMBING

In toss bombing, the aircraft is flown initially along a collision course (a straight-line path containing the target). If the bomb were released en route, gravity would cause it to fall short. To overcome this effect, the pilot pulls out of a straight-line dive and releases the bomb at a precalculated point along the pullout curve.

Toss bombing is accomplished by flying along a toss bomb path as illustrated in figure 6-6. This attack varies from dive bombing because the flight path is directed at the target for a short period, at the end of which a pullup is executed (point B). The bomb is released at a suitable point R along the pullup curve.

To relieve the pilot of the responsibility of computing and trying to maintain all the necessary conditions, several bomb directors have been devised to aid the pilot in solving the bombing problem. In toss bombing, release does not occur until after pullout has imparted to the missile a velocity whose horizontal component is the correct one for the trajectory of the bomb. The angle of attack and the dive angle are measured by a gyro which establishes a line reference. Thus, the pilot has only to control speed, or average speed, and aim the aircraft for the proper allowance.

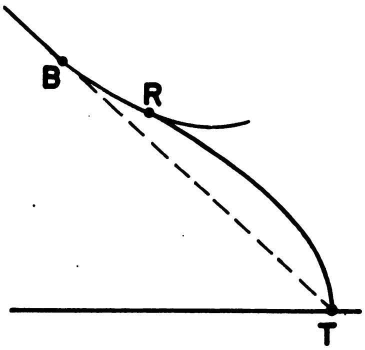

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Figure 6-6.—Toss bombing.

LOFT BOMBING

Loft bombing furnishes the best solution to the problem of dropping powerful bombs from a low altitude without endangering the dropping aircraft. Dive, toss, and glide bombing methods are inadequate for such low altitude bombing because they place the aircraft in a position where it is vulnerable both to the bomb blast and the antiaircraft fire in the target area.

The loft bombing attack uses the high speed of modern fighters and light bombers to throw the bomb from the release point to the target, giving the aircraft an opportunity to escape. The entire loft bombing attack is made at a low altitude, making it possible to evade radar tracking, and the aircraft can be well clear of the blast when the bomb goes off. If there is a low overcast, the aircraft can come in just under it and pull up into the clouds. The necessary computations and release signals for this attack are developed in the loft bombing equipment.

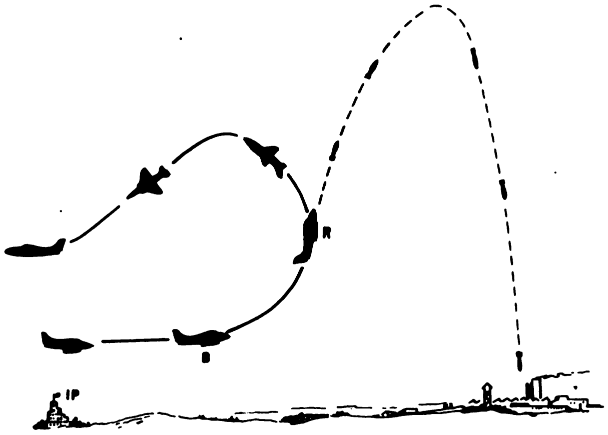

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Figure 6-7.—Loft bombing.

The attack path, as shown in figure 6-7, requires that the aircraft pass over a landmark (identification point) in direct line to the target at a specified altitude. After the elapse of a preset time interval, a pullup is executed at point B. The pullup point is determined by the characteristics of the aircraft and must be sufficient so that the aircraft will pass through the release point R at the desired climb angle.

In contrast to the toss bombing maneuver, in which no preflight planning is necessary except that required for determining line of flight with respect to the armament datum line, the loft bomb attack must be planned in detail and executed according to plan.

The release point (fig. 6-7) is determined by the speed of the aircraft at the instant of release and the desired horizontal range and altitude. In the attack the pilot flies so that the aircraft will pass over the identification point (landmark) in a direct line to the target. The approach is made in level flight at a prescribed altitude. At the instant the aircraft passes the landmark, the pilot presses a switch and keeps it depressed until actual bomb release occurs.

At the end of the preset time interval, or in other words, at the pullup point, the pilot's indicator presents the signal to indicate that the pilot should commence pullup. The pullup should be at a constant number of g's. Bomb release occurs automatically when the product of pullup acceleration, pullup time and release angle reaches a preset value. After the bomb has been released the pilot may make any desired maneuver to leave the target area.

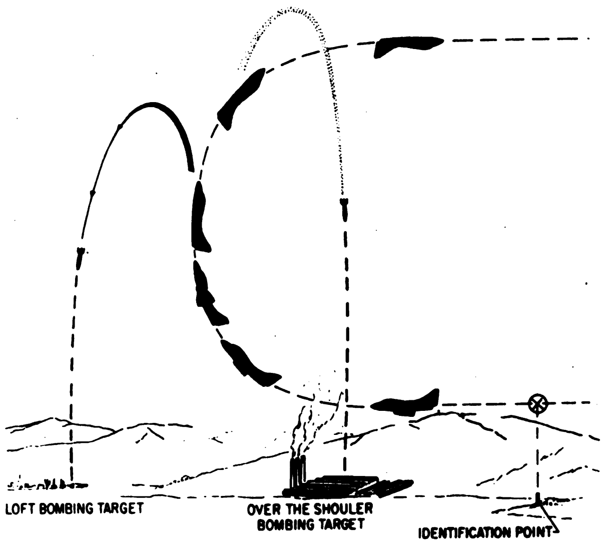

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Figure 6-8.—Over-the-shoulder bombing.

OVER-THE-SHOULDER BOMBING

In the event that the identification point is missed or cannot be used, or should the type mission require a different type attack, the attack known as over-the-shoulder may be executed. The maneuvers necessary for the pilot to perform for this type delivery is illustrated in figure 6-8. The approach to the target and the aircraft maneuvers are identical, as shown in the figure. The only difference is that in over-the-shoulder bombing the target and the identification point are the same. This means that the pilot will depress the bomb release switch when directly over the target, and the bomb is automatically released at a predetermined angle. As can be seen, the angle of release is greater than that used in loft bombing.

SUMMARY

In this chapter you have been introduced to the bombing problem. In particular, you have studied the factors or conditions that affect a bomb trajectory. You have also studied the different methods of delivery. The following is a summary of the chapter.

FACTORS AFFECTING BOMBING—In general, the required type of bombing depends upon the following:

1. Nature of target
2. Nature of ground and air defense
3. Type of damage desired to the target
4. Weather conditions over the target
5. Distance to the target

VACUUM TRAJECTORY—Three factors are necessary for the determination of range angle Φ (assume high level bombing). The three factors are aircraft velocity (V_g), altitude (H), and acceleration due to gravity (g). The variables are H and V_g, which can be computed.

AIR TRAJECTORY - NO WIND—Air resistance decreases the vertical velocity of the bomb and increases the time of fall. Air resistance also diminishes the horizontal velocity of the bomb, which causes the bomb to trail behind the vertical line of the bomber. Another factor in the determination of air resistance is the "ballistic coefficient" of the bomb.

AIR TRAJECTORY - WIND—A head wind or tail wind affects the closing speed of the bomber. A wind at an angle to the track of the bomber causes drift. (Track is the path that the bomber would follow without a crosswind.) The drift angle (θ) is formed by the heading of the bomber and the track of the bomber.

TARGET MOTION—Target velocity is resolved into components along and perpendicular to the heading of the bomber. The component of motion along the heading of the bomber gives the same effect as a head wind or a tail wind. The component of target motion across the heading of the bomber can be considered as a crosswind.

RELEASE POINT COMPUTATION—The release point problem consists of determining the course to fly and the point along that course at which the bomb must be released to hit the target. Release point computation is based upon the solution of the tracking problem and the bomb ballistic problem.

METHODS OF DELIVERY—The methods of bombing are as follows:

1. High level horizontal bombing (altitude 5,000 ft and above)
2. Low level horizontal bombing (low altitude)
3. Toss, loft, and over-the-shoulder bombing (low altitude)
4. Dive bombing

CHAPTER 7

RADAR CIRCUITS

In Chapter 1, we briefly discussed some of the aspects of the AQ rating. In the previous chapters to this point, we have discussed handtools and materials, servosystems, data sensing elements, weapon control fundamentals, and the bombing problem. In this chapter, we turn our attention to radar.

A radar system consists of a transmitter which sends out RF signals, a receiver which is located at the same site, and an indicator which gives a visual indication of echoes returned by the target. To accomplish this, many circuits, some of which are special, are required.

The circuits described in this chapter are those of a typical pulsed type radar. The major components receiving particular emphasis are the synchronizer, transmitter, receiver, and indicator.

SYNCHRONIZER

The basic function of the radar timer is to synchronize the sweep voltage or current for the indicator with the transmitter pulse. The specific function is to produce the trigger pulse that starts the transmitter, the sweep circuits, rangemark generators, blanking circuits, and gating circuits.

Timing or control is the function of the majority of the circuits in radar. Circuits in a radar set accomplish this function by producing a variety of voltage waveforms, such as square waves, sawtooth waves, trapezoidal waves, rectangular waves, brief rectangular pulses, and sharp peaks.

In sound systems and in radio, electronic circuits operate within the limits for which they are designed; but in radar timing circuits, they are often violently overdriven, frequently operating at points which range from well in the base current region to far beyond cutoff. Although all of these circuits are broadly classified as timing circuits, the specific function of any individual circuit might be timing, waveshaping, or wave generating.

Radar systems may be classified as either self-synchronized systems, or externally synchronized systems. In a self-synchronized system, the timing trigger pulses are obtained from the transmitter. In an externally synchronized system, the timing trigger pulses are obtained from a master oscillator, which is usually external to the transmitter. The master oscillator may be a sine-wave oscillator, a stable (free-running) multivibrator, or a blocking oscillator.

When a blocking oscillator is used as a master oscillator, the timing trigger pulses are usually obtained directly from the oscillator. When a sine-wave oscillator or an astable multivibrator is used as a master oscillator, pulse-shaping circuits are required to form the necessary timing trigger pulses.

In a self-synchronized radar system, the repetition rate of the timing trigger pulses is determined by the repetition rate of the modulator (or transmitter) pulses. In an externally synchronized radar system, the repetition rate of the timing trigger pulses from the master oscillator determines the pulse repetition rate of the transmitter.

Associated with every radar system is an indicator, such as a cathode-ray tube. The indicator presents target data (range, bearing, and elevation) in visual form so that the target may be located. Trigger pulses from the timer (synchronizer) are frequently used to produce gate pulses. When applied to the indicator, these gate pulses perform the following functions:

1. Initiate and time the duration of the indicator sweep voltage.

2. Intensify the cathode-ray tube electron beam during the sweep period so that the echo pulses may be displayed.

3. Gate a range mark or range marker generator so that range marker signals may be superimposed on the indicator presentation. (The terms marks and markers are normally interchangeable.)

Figure 7-1 shows the time relationship of the various waveforms in a typical radar set. The timing trigger pulses are applied to both the transmitter and the indicator. When a trigger pulse is applied to the transmitter, a short burst, or pulse, of RF energy is generated.

This energy is conducted along a transmission line to the radar antenna, from which it is radiated into space. If the transmitter energy strikes one or more reflecting targets in its path, some of the transmitted energy is reflected back to the antenna. Echo pulses from three reflecting targets at different ranges are illustrated in the part of figure 7-1 labeled "echo pulses." The corresponding receiver output signal is also shown.

The initial and final pulses in the receiver output signal are caused by the energy that leaks through the transmit-receive (TR) device when a pulse is being transmitted.

The indicator sweep voltage (fig. 7-1) is initiated at the same time that the transmitter is triggered. By delaying the timing trigger pulse fed to the indicator sweep circuit, it is possible to initiate the indicator sweep after a pulse is transmitted. (It is also possible to initiate the indicator sweep before a pulse is transmitted.)

Note, in figure 7-1, that the positive indicator-intensity gate pulse (applied to the cathode-ray tube control grid) occurs during the indicator sweep time. As a result, the cathode-ray tube trace occurs only during the sweep time and is eliminated during the flyback (retrace) time. The negative range-marker gate pulse also occurs during the indicator sweep time. This negative gate pulse is applied to a range-marker generator, which produces a series of range marks.

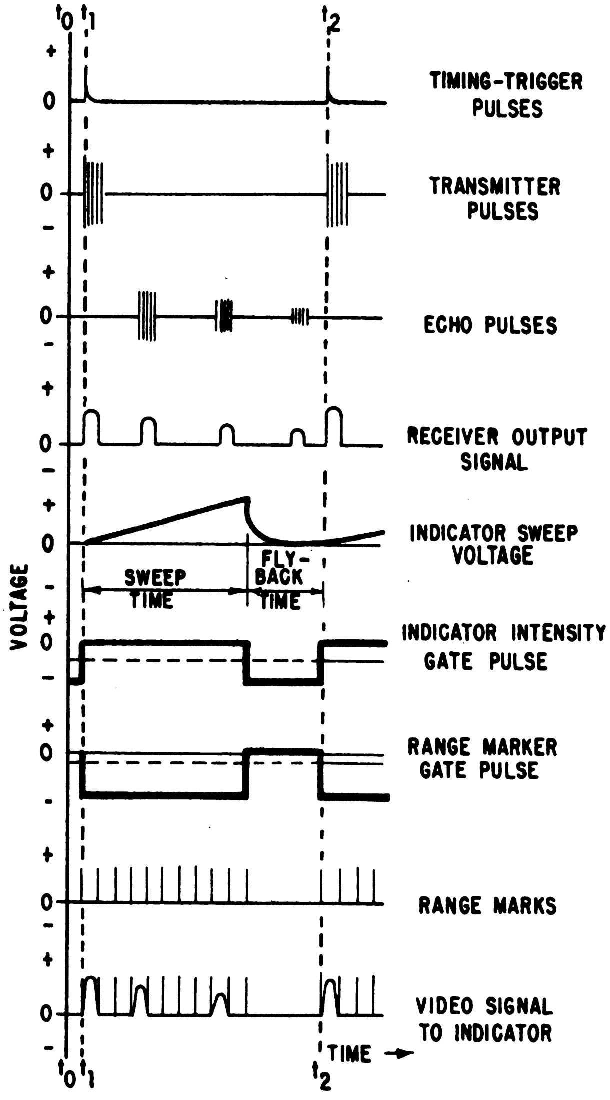

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Figure 7-1.—Time relationship of waveforms.

The range marks are equally spaced and last only for the duration of the range-marker gate pulse. When the range marks are combined (mixed) with the receiver output signal, the resulting video signal applied to the indicator may appear as shown in figure 7-1.

BASIC REQUIREMENTS

The basic timing circuit should meet three basic requirements:

1. It must be free running (astable)—since the timer is the heart of the radar, it must establish the zero time reference and the PRF.

2. It must be stable in frequency (PRF)—the PRF, or its reciprocal, the PRT, must not change between pulses for accurate ranging.

3. The frequency must be variable in steps for the radar to operate on different ranges.

There are three basic circuits that can meet the above mentioned requirements. They are the sine-wave oscillator, single-swing blocking oscillator, and the master-trigger multivibrator.

Figure 7-2 shows the block diagrams and waveforms of these three timers used in externally synchronized radar systems. Note that in each case equally spaced timing trigger pulses are produced. The repetition rate of each series of timing trigger pulses is determined by the operating frequency of the associated master oscillator.

SINE-WAVE TIMER

In the sine-wave timer (fig. 7-2(A)), a sine-wave oscillator is used for the basic timing device (master oscillator). The oscillator may be a Wien-bridge oscillator or a phase-shift

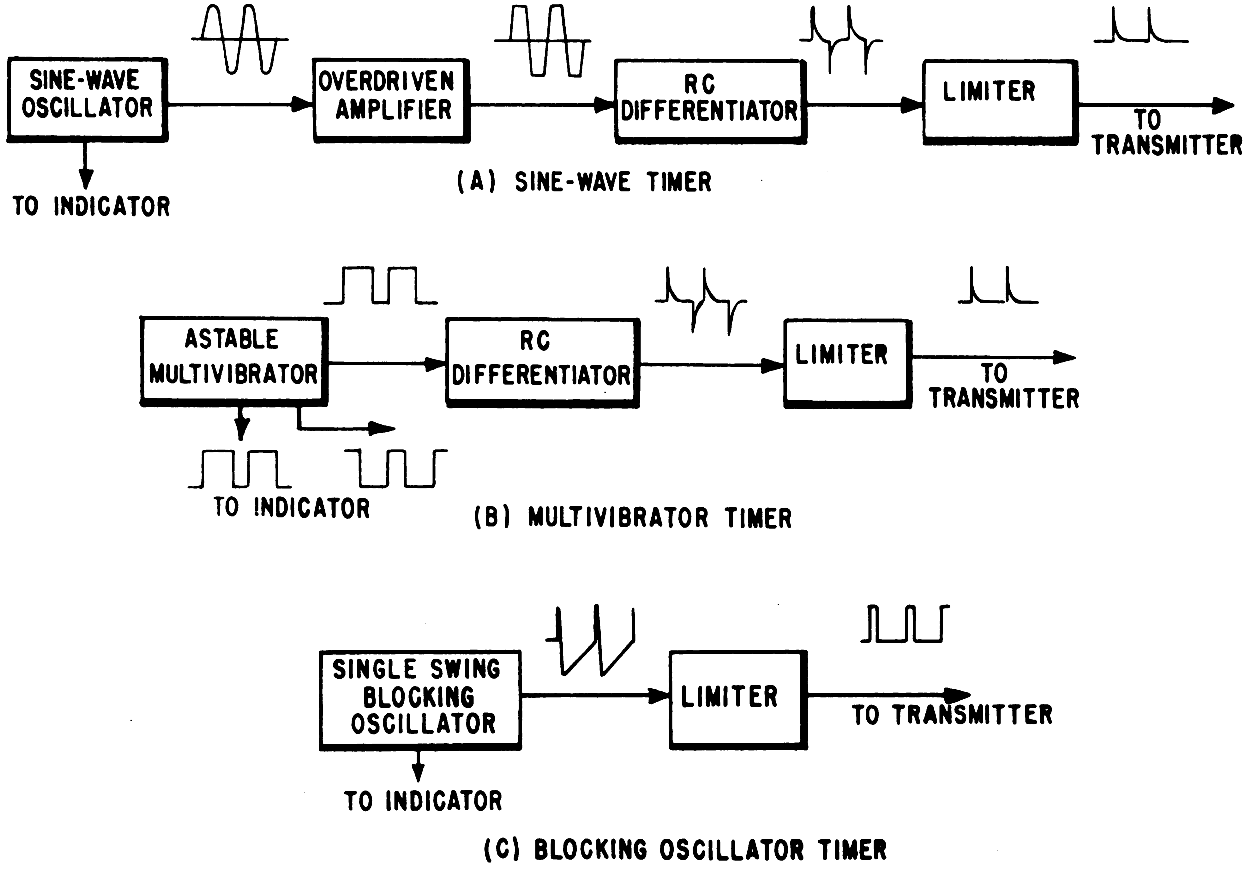

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Figure 7-2.—External timer block diagrams.

oscillator. The oscillator output is applied to both an overdriven amplifier and the radar indicator. The sine waves applied to the overdriven amplifier are converted into square waves. The square waves, in turn, are converted into positive and negative trigger pulses by means of a short-time-constant RC differentiator.

By means of a limiter, either the positive or negative trigger pulses from the RC differentiator can be removed, leaving trigger pulses of only one polarity. For example, the limiter of figure 7-2(A) is a negative-lobe limiter; that is, the limiter removes the negative trigger pulses and sends only positive trigger pulses to the radar transmitter.

One disadvantage of sine-wave timers is the large number of pulse-shaping circuits required to produce the necessary timing trigger pulses. Therefore, they are not normally found in modern weapons systems radar.

MULTIVIBRATOR TIMER

In a multivibrator timer, the master oscillator generally consists of an astable multivibrator. If the multivibrator is asymmetrical, as in figure 7-2(B), it generates rectangular waves. If the multivibrator is symmetrical, it generates square waves. In either case, the timing trigger pulses are equally spaced after the limiter removes undesired positive or negative lobes.

The output of the astable multivibrator consists of two rectangular waves. (Remember, there are two transistors in an astable multivibrator; the two collector output voltages are equal in amplitude, but 180° out of phase.) One set of rectangular pulses is applied to the RC differentiator and converted into positive and negative trigger pulses.

As in the sine-wave timer, the negative trigger pulses can be removed by means of a negative-lobe limiter. Both sets of rectangular pulses from the astable multivibrator are applied to the indicator for the following purposes:

1. One set of pulses is used to intensify the cathode-ray tube electron beam for the duration of the sweep.

2. The other set of pulses is used to gate the range marker generator. As will be shown later, rectangular pulses can also be used to produce range steps.

BLOCKING-OSCILLATOR TIMER

In the blocking-oscillator timer (fig. 7-2(C)), a free-running, single-swing blocking oscillator is generally used as the master oscillator. The advantage of the single-swing blocking oscillator is that it generates sharp trigger pulses directly. Timing trigger pulses of only one polarity are obtained by means of a limiter.

Gate pulses for the indicator circuits are produced by applying the output of the blocking oscillator to a one-shot multivibrator or a phantastron. Crystal-controlled oscillators may be used when very stable operation is required at a particular frequency.

RANGE MARKERS

The accuracy of target-range data provided by a radar varies with the use of the radar. For example, a weapons systems radar operating in its search (or map) mode needs to be accurate only within a few percent of its maximum range. However, an intercept type radar operating in its track mode must supply range data that is accurate within a few yards.

In some applications of radar, the indicator sweep is calibrated by a transparent overlay with an engraved scale. This enables the operator to estimate the range of targets. In other applications, electronic range marks are supplied to the indicator. They appear as horizontal lines on a B-scope and as concentric circles on a PPI-scope. The distance between range marks is generally determined by the type of equipment and its mode of operation.

In a weapons systems radar that requires extremely accurate target-range data, a movable range marker may be used. The range marker is obtained from a range marker generator and may be a movable range gate or range step. When a PPI-scope is used, a range circle of adjustable diameter is used to measure range accurately. In some cases, movement of the range marker is accomplished by turning a calibrated control from which range readings are obtained. In other cases, the range marker may be used as a range gate for automatic range tracking. In this case there may be no direct range readout, or the readout may be a voltmeter calibrated in range and to which range voltage, equivalent to range marker position, is applied.

This discussion describes the operation of three types of range marker generators: the range gate generator; the range marker generator; and the range step generator. The range gate generator, used in conjunction with a blocking oscillator, generates a movable range gate. The range marker generator and the range step generator, used in conjunction with an astable multivibrator, generate fixed range marks and a movable range step, respectively.

Range Gate Generator

Figure 7-3 shows a simplified block diagram of a typical radar synchronizer that includes a range gate generator. The indicator is a B-scope with the range deflection voltages applied to the vertical plates. Scopes are discussed later in this chapter.

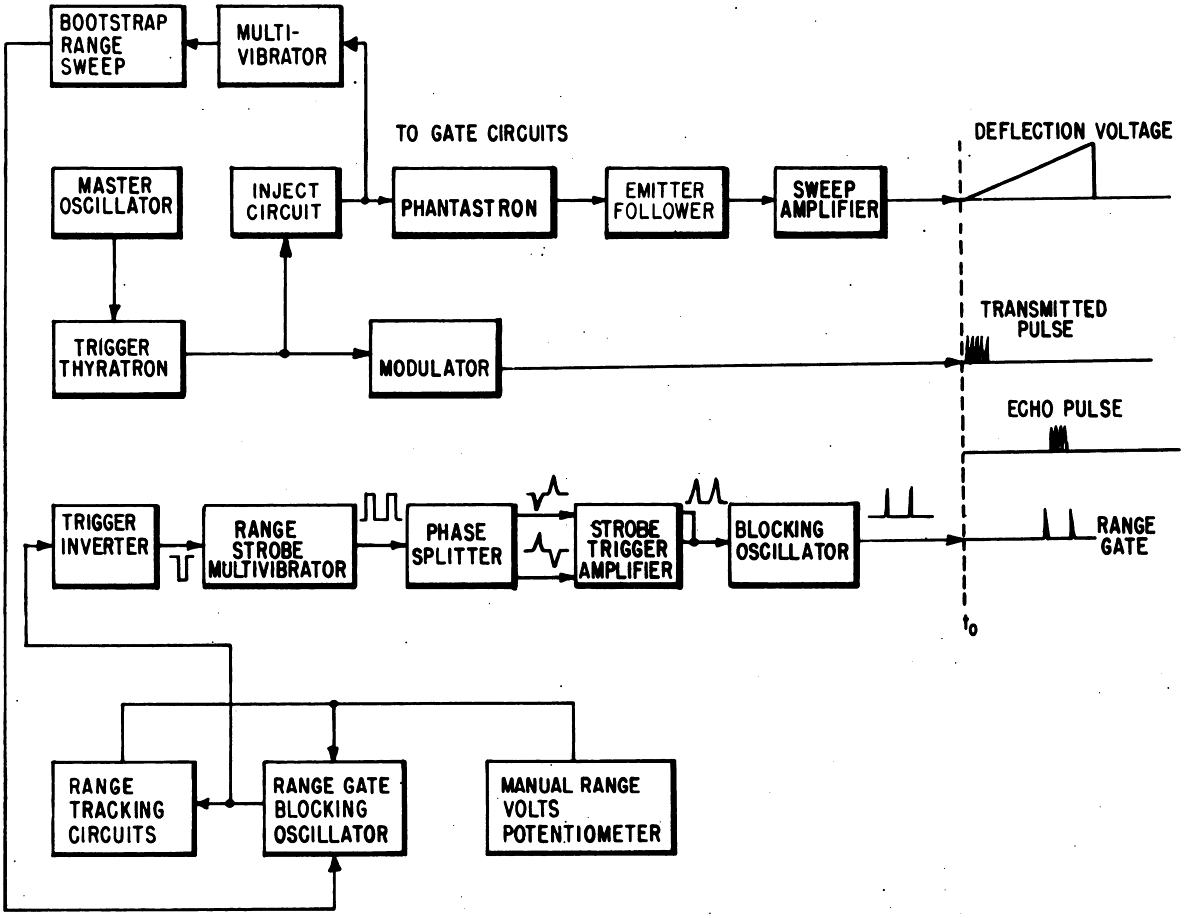

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Figure 7-3.—Synchronizer with range gate generator.

The PRF is controlled by a master oscillator, or multivibrator, whose output is coupled to a thyratron trigger. The output of the thyratron trigger is used to trigger the radar modulator and the B-scope sweep circuits, thus starting the transmitting pulse and the range sweep at the same instant.

The phantastron in the sweep circuits is a timing circuit that supplies a sweep sawtooth to the sweep amplifier. The width of the gate and sawtooth is dependent on the range selected by the operator.

The range gate circuit receives its input pulse from the trigger thyratron and generates a delayed range gate pulse. The delay of this pulse from t_0 is dependent on the position of the target in range when tracking, or on the manual positioning of the range volts potentiometer by the operator when in the search mode. The range gate triggers the range strobe multivibrator, whose output is amplified and sent to the blocking oscillator that sharpens the pulses as shown in figure 7-3. This range gate is used to select the target to be tracked and, when in track mode, brightens the trace or brackets the target (depending on the system) to indicate which target is being tracked.

Range Marker Generator

Figure 7-4 is a block diagram of a typical range marker generator. This range marker generator consists of a ringing oscillator Q1611-Q1612, an emitter follower Q1613, a countdown multivibrator Q1616-Q1617, and a pulse forming amplifier Q1614. Generation of the marks commences at the ringing oscillator which is excited into operation by incoming trigger pulses, thereby producing a sinusoidal output which is synchronized to the trigger pulses. This sinusoidal output is applied to the emitter follower, which provides interstage buffering by isolating the ringing oscillator from the countdown multivibrator. The output coupling circuit of the emitter follower shifts the average output level to zero (ground) and clips the negative going portions of the signal, allowing only the positive half of each sine wave to reach the countdown multivibrator. The countdown multivibrator receives a high-frequency positive trigger corresponding to a fixed interval. The countdown multivibrator is driven by this input to develop a negative pulse train, the period of which is controlled by the range marks select switch. This negative output is applied to the pulse forming amplifier where it is reshaped and passed on to a marker mixer.

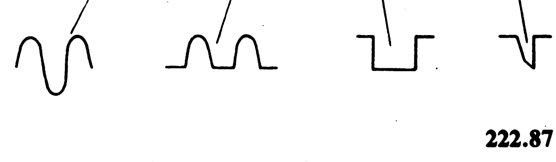

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Figure 7-4.—Range marker generator.

The output of a range marker generator can be applied directly to one of the deflection plates on an A-scope. In this case, range marker pulses appear simultaneously with the radar echo signals, and permit estimation of target range. In B-scope and PPI-scope applications, the output of the range marker generator is applied to a video mixer. In this case, radar echo signals are combined with marker signals before being applied to the grid of the CRT.

Range Step Generator

Examine figure 7-5, the schematic diagram and waveforms of a typical range step generator. The range step generator consists of a sawtooth voltage generator Q1, a negative clipper CR1, and a limiting amplifier. Diode CR1 is frequently referred to as a pickoff diode. The position of the range step along the indicator time base is controlled by potentiometer R3. When the range step coincides with the leading edge of a target echo pulse, the target range can be read directly from a calibrated range dial associated with R3.

Between times t_0 and t_1 (fig. 7-5(B)), the base of transistor Q1 is at ground potential (zero volts).

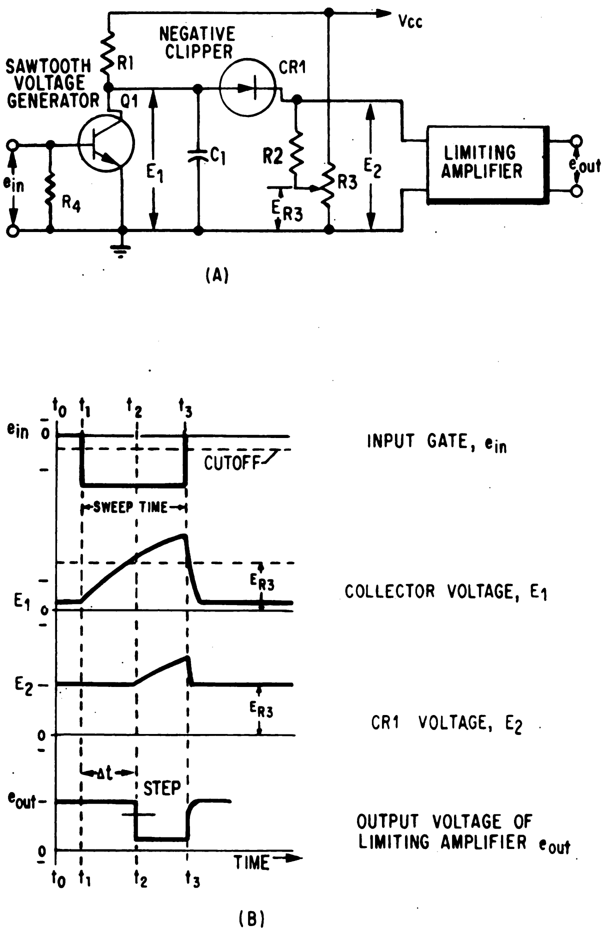

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Figure 7-5.—Range step generator with pickoff diode. (A) Schematic diagram; (B) waveforms.

As a result, Q1 conducts and the Q1 collection voltage (E_1) equals Q1 collector-supply voltage (Vcc) minus the voltage drop across the load resistor R1. The horizontal dashed line across the E_1 waveform indicates the E_{R3} voltage (fig. 7-5(A)) at the adjustable tap of potentiometer R3. Since E_1, is less than E_{R3} between times t_0 and t_1, the anode of the negative clipper CR1 is less positive than the CR1 cathode, and CR1 does not conduct. Hence the CR1 cathode voltage (E_2) equals E_{R3}, the voltage at the R3 tap.

Between times t_1 and t_3, the base of transistor Q1 is driven below cutoff. As a result, Q1 ceases to draw collector current. When no collector current flows in Q1, the capacitor C1 charges through the Q1 load resistor R1, and the collector voltage of Q1 (E_1) rises exponentially toward the Q1 collector-supply voltage (Vcc). At time t_2, E_1 exceeds E_{R3}, and diode CR1 conducts. If the CR1 anode resistance is small, the CR1 cathode voltage (E_2) practically equals E_1 between times t_2 and t_3.

Following time t_3 the base of Q1 returns to ground potential, and Q1 again conducts. As a result, capacitor C1 discharges through Q1, and the Q1 collector voltage decays exponentially toward its initial value. As soon as E_1 becomes less than E_{R3}, CR1 no longer conducts, and the CR1 cathode voltage again equals E_{R3}.

When the E_2 waveform is amplified and limited by the limiting amplifier, the amplifier output-voltage (e_{out}) waveform appears as in figure 7-5(B). Note that a nearly vertical edge (step) appears in the e_{out} waveform the instant CR1 begins to conduct (time t_2).

By varying the setting of the R3 tap, the instant at which CR1 conducts can be varied. The position of the range step, therefore, can be controlled by adjusting the setting of R3. If a linear relationship is to be established between the delay of the step (Δt) and the voltage at the R3 tap (E_{R3}), the Q1 sawtooth collector voltage must be linear.

The e_{out} waveform is applied to the vertical-deflection plates of a cathode-ray tube. Only the portion of the e_{out} waveform that occurs between times t_1 and t_3 is displayed on the cathode-ray tube screen. Remember, the indicator trace is blanked out during the flyback (retrace) time.

TRANSMITTER

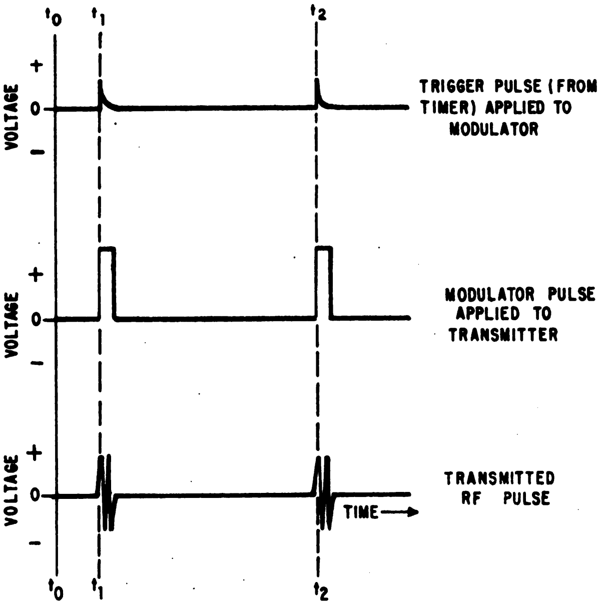
The purpose of the transmitter is to develop high-power, high-frequency pulses of RF energy which are radiated into space by the antenna system. Several types of transmitting devices are used in fire control radar. Among these are magnetrons, klystrons, traveling wave tubes, and gallium arsinide (Gunn) oscillators. The construction, operating characteristics, and limitations of these devices are covered in *Basic Electronics*, Volume 2, NAVEDTRA 10087-(Series), Chapter 8.

Basically, the transmitter is an RF oscillator which is turned on and off in accordance with a signal received from a modulator. The oscillator is not normally controlled directly by the signal from the timer; instead, the timer triggers the modulator which, in turn, switches the transmitter on and off.

RADAR MODULATOR

The modulator controls the radar pulse width by means of a rectangular dc pulse (modulator pulse) of the required duration and amplitude. The peak power of the transmitted (RF) pulse depends on the amplitude of the modulator pulse.

Figure 7-6 shows the waveforms of the trigger pulse applied by the timer to the modulator, the modulator pulse applied to the radar transmitter, and the transmitted RF pulse.


t_0
t_1
t_2
VOLTAGE
+
0
−
TRIGGER PULSE (FROM TIMER) APPLIED TO MODULATOR
VOLTAGE
+
0
−
MODULATOR PULSE APPLIED TO TRANSMITTER
VOLTAGE
+
0
−
TRANSMITTED RF PULSE
TIME→
t_0
t_1
t_2

222.89

Figure 7-6.—Radar pulse waveforms.

Note the following:

1. The modulator pulse is applied to the transmitter the instant the modulator receives the trigger pulse from the timer.

2. The modulator pulse is flat on top.

3. The modulator pulse has very steep leading and trailing edges.

Remember, for accurate determination of target range, the timing circuit must be triggered the instant the leading edge of the transmitted RF pulse leaves the transmitter. Thus, the trigger pulse that controls the operation of the modulator also synchronizes the cathode-ray tube sweep circuits and target range measuring circuits.

There are two types of modulators, the line-pulsing modulator and the drive-hard-tube modulator. The line-pulsing modulator stores energy and forms pulses in the same circuit element. This element is usually the pulse forming network. The drive-hard-tube modulator forms the pulse in the driver; the pulse is then amplified and applied to the modulator. The drive-hard-tube modulator has been replaced by the line-pulsed modulator. The reasons for this replacement are that the drive-hard-tube modulator has lower efficiency, its circuits are more complex, higher power supply voltage is required, and it is more sensitive to voltage changes.

The line-pulsed modulator is easier to maintain because of its less complex circuitry and, for a given amount of power output, it is more compact and light. Since it is the principally used modulator in aviation radar, it is the one that we discuss.

Figure 7-7 shows the basic components of a radar modulator. Note that the components of the radar modulator are as follows:

1. A power supply.

2. A storage element (a circuit element or network for storing energy).

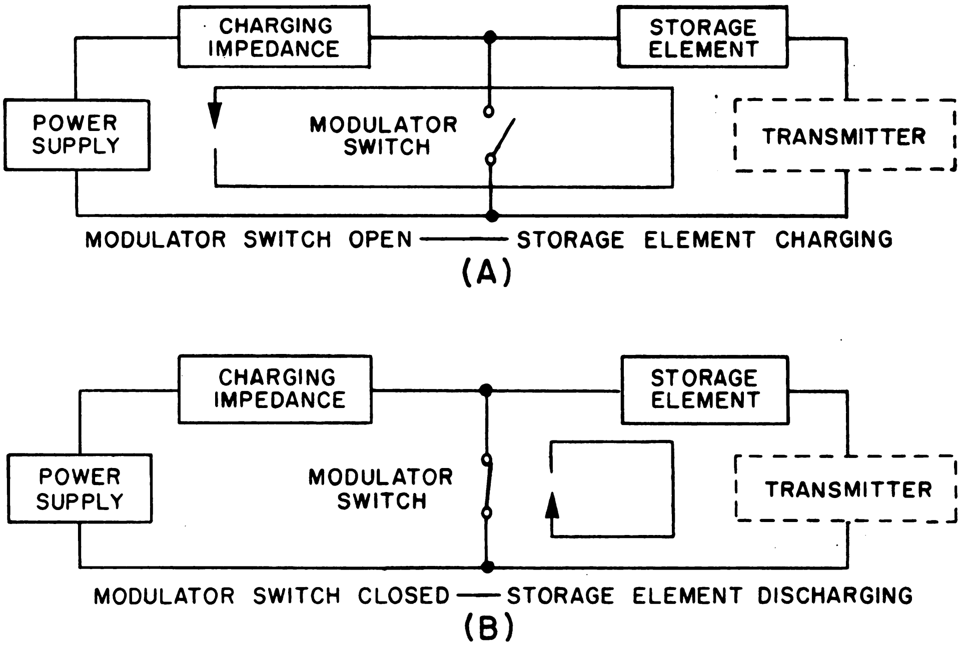


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Figure 7-7.—Basic radar modulator block diagram. (A) Modulator switch open; (B) modulator switch closed.

3. A charging impedance (to control the charge time of the storage element and to prevent short-circuiting of the power supply during the modulator pulse).

4. A modulator switch (to discharge the energy stored by the storage element through the transmitter oscillator during the modulator pulse).

Figure 7-7(A) shows the modulator switch open and the storage element charging. With the modulator switch open, the transmitter produces no power output, but the storage element stores a large amount of energy. Figure 7-7(B) shows the modulator switch closed and the storage element discharging through the transmitter. The energy stored by the storage element is released in the form of a high-power, dc modulator pulse. The transmitter converts the dc modulator pulse to an RF pulse, which is radiated into space by the radar antenna. Thus, the modulator switch is closed for the duration of a transmitted RF pulse, but is open between pulses.

Many different kinds of components are used in radar modulators. The power supply generally produces a high-voltage output, either alternating or direct current. The charging impedance may be a resistor or an inductor. The storage element is generally a capacitor, an artificial transmission line, or a pulse-forming network. The modulator switch is usually an electron tube.

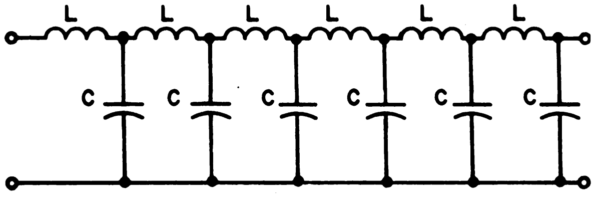
Modulator Storage Elements

Capacitor storage elements are used only in modulators that have a dc power supply and an electron-tube modulator switch.

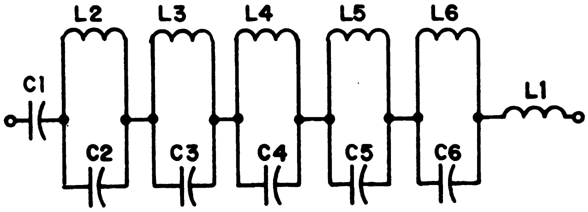
The capacitor storage element is charged to a high voltage by the dc power supply, and releases only a small part of its stored energy to the transmitter. The electron-tube modulator switch controls the charge and discharge of the capacitor storage element.

The artificial transmission line storage element (fig. 7-8(A)) consists of identical capacitors (C) and inductors (L), arranged to simulate sections of a transmission line. The purposes of the artificial transmission line are to store energy when the modulator switch is open (between transmitted RF pulses), and to discharge and form a rectangular dc pulse (modulator pulse) of the required duration when the modulator switch is closed.

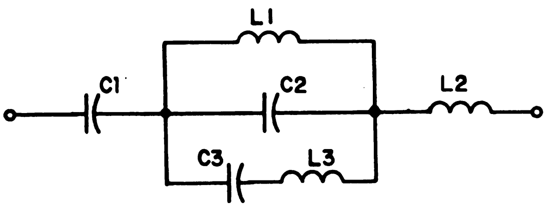
The duration of the modulator pulse depends on the values of inductance and capacitance in each LC section of the artificial transmission line (fig. 7-8(A)) and the number of LC sections used. Other arrangements of capacitors and inductors (pulse-forming networks) are very similar in operation to artificial transmission lines.



(A) ARTIFICIAL TRANSMISSION LINE



(B) PULSE—FORMING NETWORK



(C) PULSE—FORMING NETWORK

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Figure 7-8.—Types of modulator storage elements.

CAPACITOR.—Figure 7-9(A) is the schematic diagram of a modulator that uses a single capacitor (C1) as its storage element. The charge and discharge of C1 is controlled by transistor Q1 which is a switching transistor normally held below cutoff by a negative dc bias applied to its base.

When a positive trigger pulse (from the radar timer) is applied to the base of Q1, Q1 conducts for the duration of the trigger pulse. When Q1 is cut off, storage capacitor C1 charges through the series circuit consisting of the dc power supply, charging impedance Z1, and charging diode CR1. The low voltage across CR1 effectively prevents the RF oscillator from operating.

When a positive trigger pulse is applied to the base of Q1, Q1 suddenly conducts, and C1 discharges. The discharge path (fig. 7-9(A)) is a series circuit consisting of switching transistor Q1 and the RF oscillator. Note that discharge current I2 is opposite in direction to charge current I1. Since charging diode can conduct in only one direction (from cathode to anode), CR2 remains cut off during the modulator pulse. Thus discharge current I2 flows through the RF oscillator, and an RF pulse is generated by the oscillator.

During the modulator pulse, storage capacitor C1 discharges, and the C1 voltage decreases. Since the C1 voltage (modulator pulse) is applied to the RF oscillator, the frequency of the oscillator changes if there is any significant change in the C1 voltage. To keep the C1 voltage practically constant, C1 must have a large capacitance. Thus, only a small fraction of the charge is removed from C1 during the modulator pulse, and the C1 voltage remains practically constant.

The switching transistor starts and stops the modulator pulse. Thus, the width (duration) of the modulator pulse depends on the width of the trigger pulse applied to the base of Q1. The pulse repetition rate depends on the rate at which trigger pulses are applied to the base of Q1. To obtain a modulator pulse with nearly vertical sides (a dc rectangular pulse), the trigger pulse must also have nearly vertical sides. Modulators that use capacitor

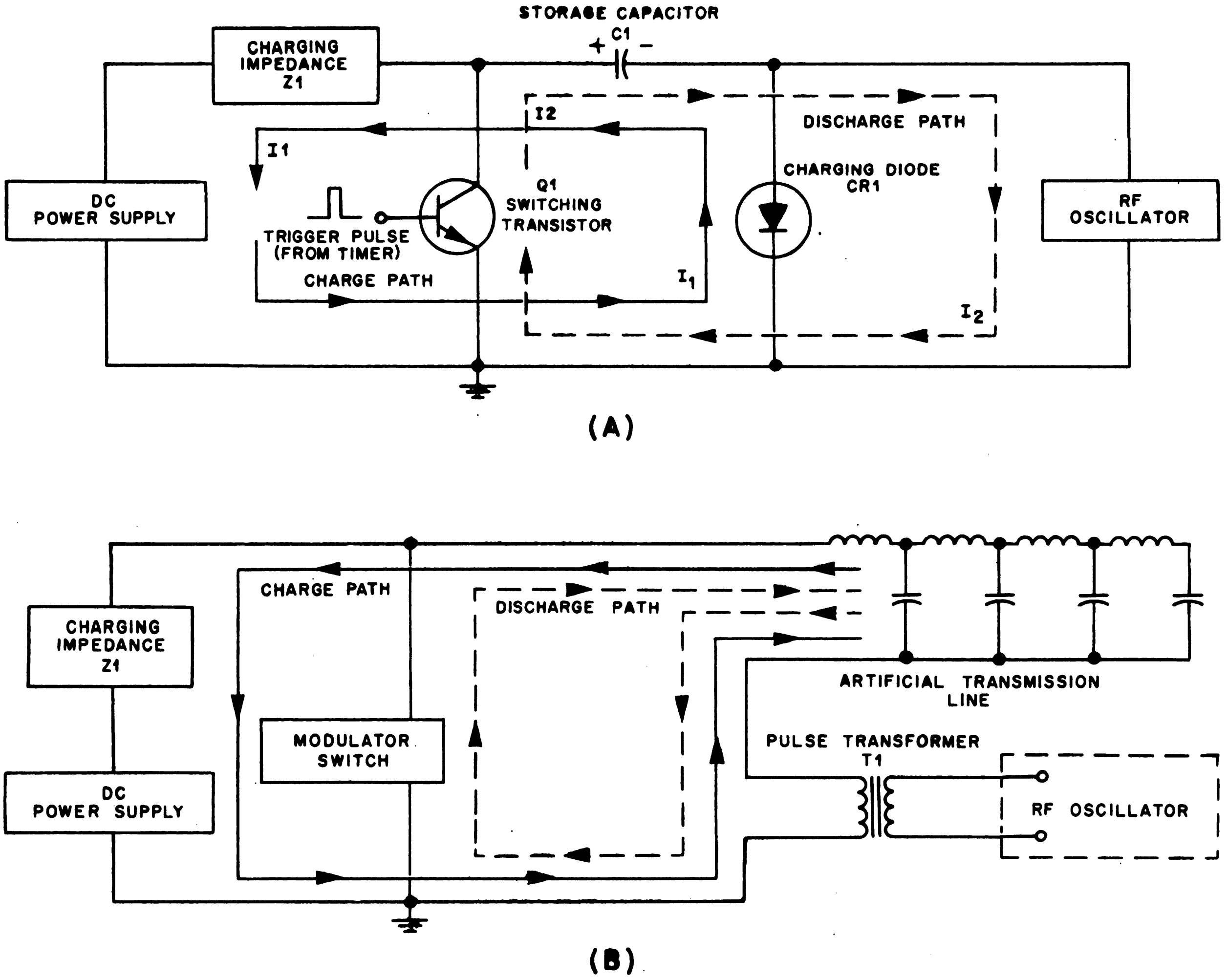

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Figure 7-9.—Applications of basic modulator elements. (A) Single capacitor; (B) artificial transmission line.

storage elements and switching transistors as switches have the following advantages:

1. The pulse repetition rates can be varied over relatively wide limits.

2. The pulse width can also be varied over relatively wide limits.

ARTIFICIAL TRANSMISSION LINE.—Examine figure 7-9(B), which shows a radar modulator that uses an artificial transmission line as its storage element. A switch (modulator switch) controls the pulse repetition rate. When the modulator switch is open (between modulator pulses), the transmission line charges.

The charge path includes the primary of pulse transformer T1, the dc power supply, and charging impedance Z1. When the modulator switch is closed, the transmission line discharges through the series circuit consisting of the modulator switch and the primary of pulse transformer T1.

The artificial transmission line is effectively an open circuit at its output end. Thus, when the voltage wave reaches the output end of the line, it is reflected. As the reflected wave propagates from the output end toward the input end of the line, it completely discharges each section of the line. When the reflected wave reaches the input end of the line, the line is completely discharged, and the modulator pulse ceases abruptly. If the oscillator and pulse transformer circuit impedance is properly matched to the line impedance, then the voltage pulse that appears across the T1 primary is one-half the voltage to which the line was charged initially.

The width of the pulse generated by an artificial transmission line depends on the time required for a voltage wave to travel from the input end to the output end of the line and back. Thus, the pulse width depends on the velocity of propagation along the line (determined by the inductance and capacitance of each section of the line) and the number of line sections (the length of the line).

PULSE-FORMING NETWORKS.—A pulse-forming network is similar to an artificial transmission line because it stores energy between pulses and produces an almost rectangular pulse. The pulse-forming network (fig. 7-8(B)) consists of inductors and capacitors arranged so that they approximate the behavior of an artificial transmission line.

Each capacitor in the artificial transmission line (fig. 7-8 (A)) must carry the high voltage required for the modulator pulse. Since each capacitor must be insulated for this high voltage, an artificial transmission line consisting of many sections is bulky and cumbersome.

The pulse-forming network (fig. 7-8(B)) can carry high voltage but does not require bulky insulation on all of its capacitors. Only series capacitor C1 must be insulated for high voltage. Since the other capacitors are in parallel with the corresponding inductors, the modulator pulse voltage divides nearly equally among them. Thus, except for C1, the elements of the pulse-forming network are relatively small.

Pulse-forming networks are often insulated by immersing each circuit element in oil. The network is usually enclosed in a metal box, on which the pulse length, characteristic impedance, and safe operating voltage of the network are marked. If one element in such a network fails, the entire network must be replaced.

Switching Devices

The voltage stored in a storage-element capacitor, artificial transmission line, or pulse-forming network must be discharged through a switching device. The switching device conducts for the duration of the modulator pulse, and is open-circuited between pulses. Thus, the modulator switch must perform the following functions:

1. Close suddenly, and reach full conduction in a small fraction of a microsecond.
2. Conduct large currents (tens or hundreds of amperes), and withstand large voltages (thousands of volts).
3. Cease conducting (become an open circuit) with the same speed that it starts to conduct.
4. Consume only a very small fraction of the power that passes through it.

These requirements are met best by the thyratron tube (gas-filled).

The thyratron, normally held below cutoff by a negative grid voltage, conducts when a positive trigger pulse is applied to its grid. Once fired, the thyratron continues to conduct as long as the storage element (artificial transmission line or pulse-forming network) is discharging.

During discharge of the storage element, the gas in the thyratron is highly ionized. While the storage element discharges, the plate-to-cathode resistance of the thyratron is practically zero. When the storage element is completely discharged, current ceases to flow through the thyratron and the gases become deionized. Thus, the negative grid bias regains control, and the thyratron is cut off (the modulator switch opens).

Most radar modulators use a high-voltage, dc power supply. Typical dc power supplies for radar modulators use a half-wave rectifier, a full-wave rectifier, or a bridge rectifier.

The modulator charging impedance (fig. 7-10(A)) prevents the dc power supply from becoming short-circuited when the modulator switch closes. When the modulator switch is open, the charging impedance also controls the rate at which the storage element charges. When the charging impedance is large, the storage element charges slowly. When the charging impedance is small, the storage element charges rapidly.

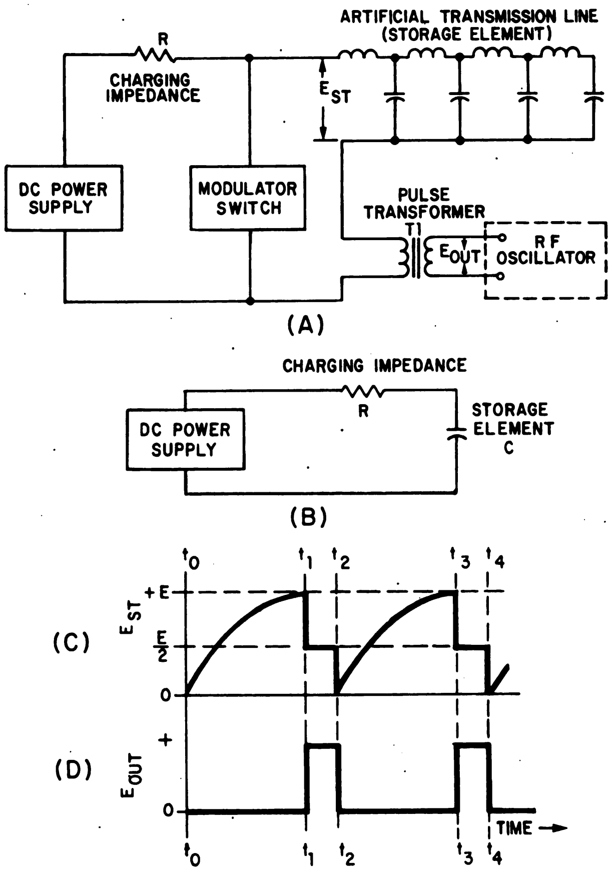

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Figure 7-10.—**Radar modulator with resistance charging. (A) Schematic diagram; (B) equivalent charge circuit; (C) storage element voltage (E_{st}) waveform; (D) T_1 secondary voltage (E_{out}) waveform.**

Many different kinds of charging impedance and charging circuits are used in radar modulators. The type of charging impedance and charging circuit used depends on the following:

1. The type of power supply (ac or dc).
2. The type of storage element.
3. The modulator pulse voltage required.
4. The pulse repetition rate.
5. The frequency of the available ac supply voltage.

Most radar modulators charge very slowly compared with the rate at which they discharge. (The interval between modulator pulses is much longer than the pulse width.) Because the charging current is relatively small and changes very slowly, inductances in a modulator storage element have negligible effect on charging. Thus, all modulator storage elements can be represented as a capacitor during their charging interval, as in figure 7-10(B).

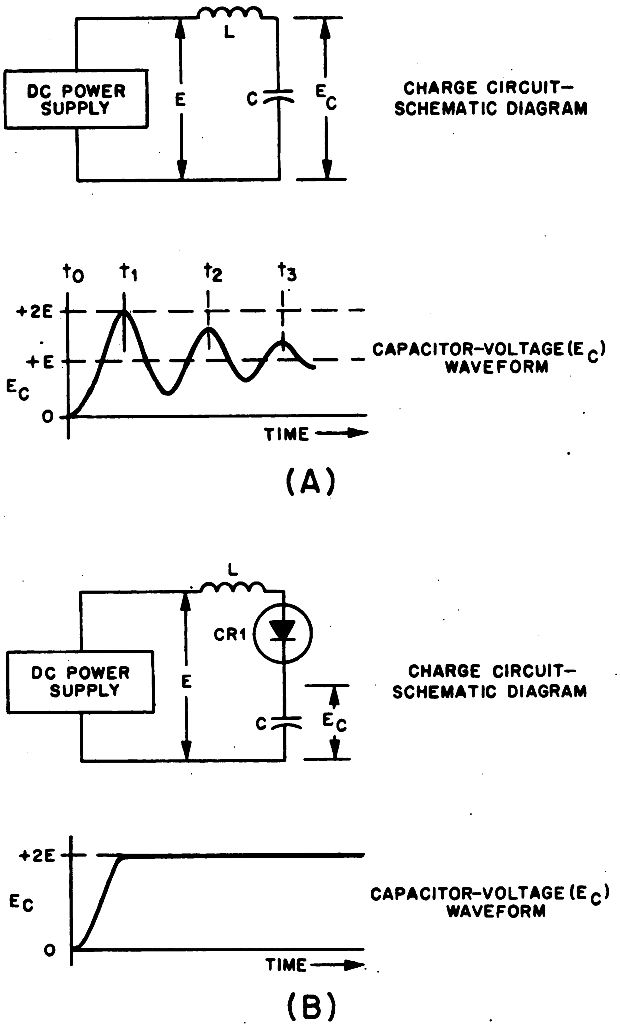
RESISTANCE CHARGING.—In figure 7-10(B) (the equivalent charging circuit of the radar modulator) note that a capacitor C represents the storage element (artificial transmission line) of the modulator. A resistor R represents the charging impedance. When the modulator switch is open, the storage element charges, along a typical RC charge curve, to a maximum voltage, E (time interval t_1 - t_1, fig. 7-10(C)).

When the modulator switch is closed (time t_1), the storage-element voltage (E_{st}) decreases to E/2. (Remember, if an artificial transmission line or pulse-forming network is charged to a maximum voltage, E, and a matching impedance load is suddenly connected across the line, the line voltage decreases instantly to E/2). Voltage E_{st} remains at E/2 for the duration of the modulator pulse (time interval t_1 - t_2). At the end of the modulator pulse (time t_2), voltage E_{st} suddenly decreases to zero. Shortly afterwards, the modulator switch opens, and a new charging cycle begins.

With the storage element charging (time interval t_0 - t_1), the change in current through T1 pulse-transformer primary (fig. 7-10(A)) is too slow to produce an output voltage. Thus, the T1 secondary voltage E_{out} (fig. 7-10(D)) is zero. When the modulator switch closes (time t_1), the rapid decrease in storage-element voltage (E_{st}, fig. 7-10(C)) appears across the T1 primary and induces a high voltage in the T1 secondary.

During the modulator pulse (time interval t_1 - t_2), voltage E_{out} remains constant. At the end of the pulse (time t_2), T1 secondary voltage decreases suddenly to zero. Thus, pulse transformer T1 converts the rapidly changing storage-element voltage to a steep, high-voltage pulse.

RESONANCE CHARGING.—If the charging resistor is replaced by an inductor, the charging circuit becomes series resonant. When a dc voltage is applied to a series-resonant circuit (fig. 7-11(A)), capacitor C begins charging through inductance L. When E_c approaches the applied dc voltage E, the magnetic lines of force due to current flow through L begin collapsing and sustain the charging current. In this way capacitor voltage E_c rises to its maximum value, which is twice the applied dc voltage, E. (Due to circuit losses in actual practice, this voltage is approximately 1.9E.) The capacitor voltage then oscillates at the resonant frequency of the LC circuit. These oscillations gradually decay until E_c becomes constant, and equals E, the applied dc voltage. This is called dc resonance charging.


L
DC POWER SUPPLY
E
C
E_C
CHARGE CIRCUIT–SCHEMATIC DIAGRAM
t0
t1
t2
t3
+2E
+E
E_C
0
TIME
CAPACITOR-VOLTAGE (E_C) WAVEFORM
(A)
L
CR1
DC POWER SUPPLY
E
C
E_C
CHARGE CIRCUIT–SCHEMATIC DIAGRAM
+2E
E_C
0
TIME
CAPACITOR-VOLTAGE (E_C) WAVEFORM
(B)

222.94

Figure 7-11.—(A) dc resonance charging; (B) resonance charging with a diode.

Dc resonance charging is used only when the pulse repetition period corresponds to the resonant frequency of the LC circuit. For example, with dc resonance charging, the modulator switch closes at the instant the capacitor voltage reaches its maximum value (time t_1, fig. 7-11(A)). The advantage of dc resonance charging is that it permits the storage element to be charged to a voltage twice the dc power-supply voltage. Its disadvantage is that the pulse repetition rate is fixed by the resonant frequency of the LC charging circuit.

Addition of a diode to the resonant charging circuit permits the storage element to charge to a dc voltage twice the applied dc voltage, and as a result, E_c increases to its maximum value (2E), and then remains constant. Look at figure 7-11(B), the schematic diagram and the capacitor voltage (E_c) waveform of a resonant charging circuit that uses a diode. Note that diode CR1 is connected in series with the charging impedance (inductor L) and the storage element (represented by capacitor C). Since CR1 can conduct in only one direction, capacitor C is charged through the dc power supply. The storage element (C) can be discharged at any time after E_c reaches its maximum value. Thus, the pulse repetition rate can be varied over a wide range.

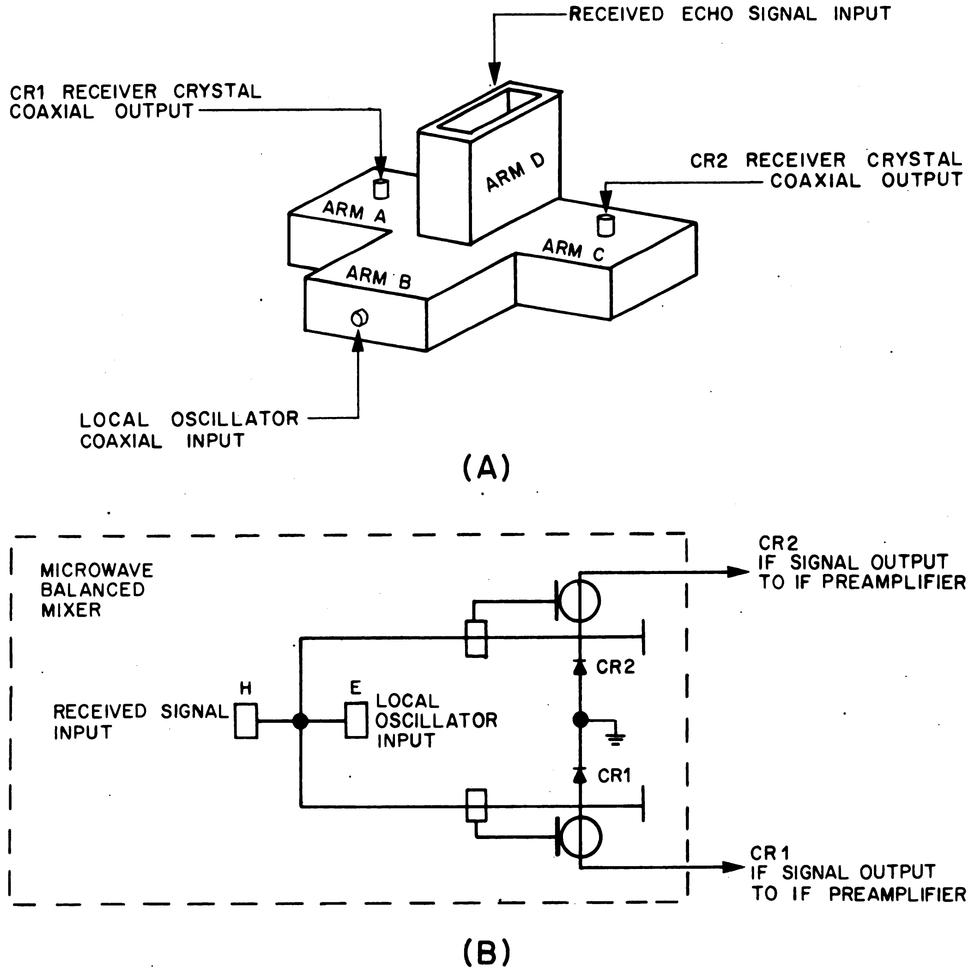
RECEIVER

Because the received RF echo pulses are very small, the radar receiver must have high-gain and low-noise capabilities. Due to the noise produced by RF amplifier stages at microwave frequencies, radar receivers are modified slightly. Instead of RF amplifier stages, the typical radar receiver uses a waveguide balanced mixer (microwave mixer), and an IF preamplifier to produce the gain normally achieved by RF amplifier stages, but with much less inherent noise.

MICROWAVE MIXER

The typical radar receiver microwave mixer is a waveguide balanced mixer. (See figure 7-12(A) & (B).) This section of waveguide forms a hybrid junction (also referred to as "hybrid T" or "magic T"). It is a waveguide arrangement with four branches, so constructed that energy (signals) entering one of the four branches is coupled to only two of the three remaining branches. In figure 7-12(A) the four branches are labeled "ARM A," "ARM B," "ARM C," and "ARM D." The receiver crystals (CR1 and CR2) are inserted directly into the waveguide, and coaxial probes are used to couple the output signals. The crystals are located one-quarter wavelength from their respective short-circuited waveguide ends; that is, the point of maximum voltage along a tuned line. The crystals are also connected to an impedance network located in the IF preamplifier. This network can be adjusted for optimum coupling and best noise figure.

The local oscillator signal is injected into Arm B (fig. 7-12(A), by a coaxial probe. The signal is


RECEIVED ECHO SIGNAL INPUT
CR1 RECEIVER CRYSTAL COAXIAL OUTPUT
ARM D
CR2 RECEIVER CRYSTAL COAXIAL OUTPUT
ARM A
ARM C
ARM B
LOCAL OSCILLATOR COAXIAL INPUT
(A)
MICROWAVE BALANCED MIXER
CR2 IF SIGNAL OUTPUT TO IF PREAMPLIFIER
CR2
H
E
RECEIVED SIGNAL INPUT
LOCAL OSCILLATOR INPUT
CR1
CR1 IF SIGNAL OUTPUT TO IF PREAMPLIFIER
(B)

222.537

Figure 7-12.—(A) waveguide balanced mixer; (B) waveguide balance mixer schematic diagram.

distributed as shown in figure 7-13. You will note that the local oscillator signal is in phase across the crystals. The received signal is injected into Arm D (fig. 7-12(A)) by waveguide connection from the antenna. The signal is distributed as shown in figure 7-13(B). Note the signal is out of phase across the crystals. The resulting fields are illustrated in figure 7-13C.

Since there is a difference in phase between the received signals applied across the two crystals, and because the local oscillator signal is in phase across both crystals, there will be a condition when both signals applied to CR1 will be in phase and the signals applied to CR2 will be out of phase. This results in an IF frequency (difference between local oscillator and received signal frequencies) signal of one polarity across CR1 and of the opposite polarity across CR2. When these two signals are applied to the input circuit of an IF preamplifier, they will add; outputs of the same polarity will cancel each other. It is this action which helps to eliminate inherent local oscillator noise. The IF preamplifier will be discussed later in this chapter.

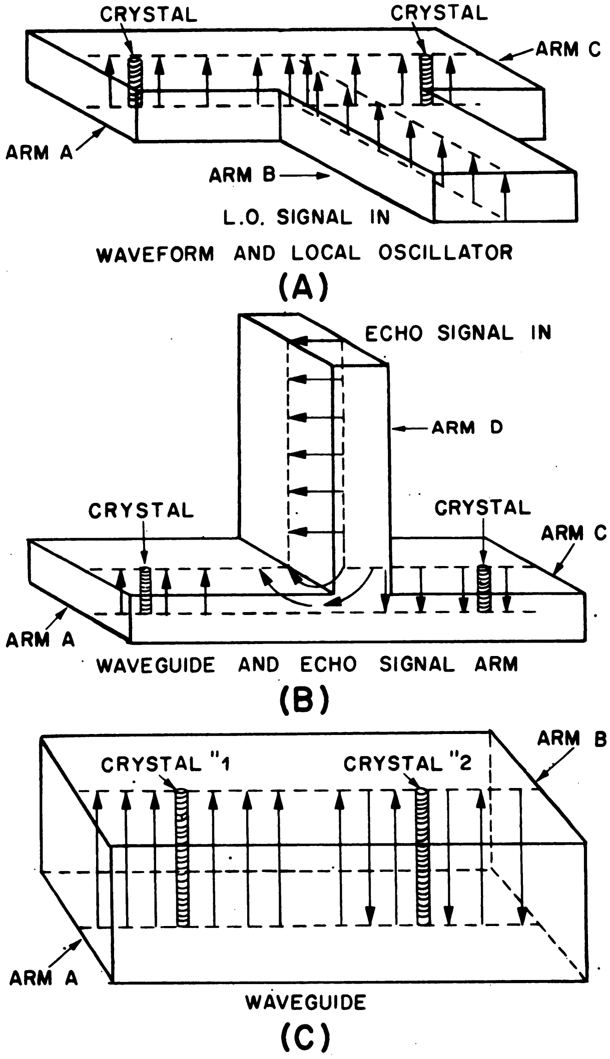


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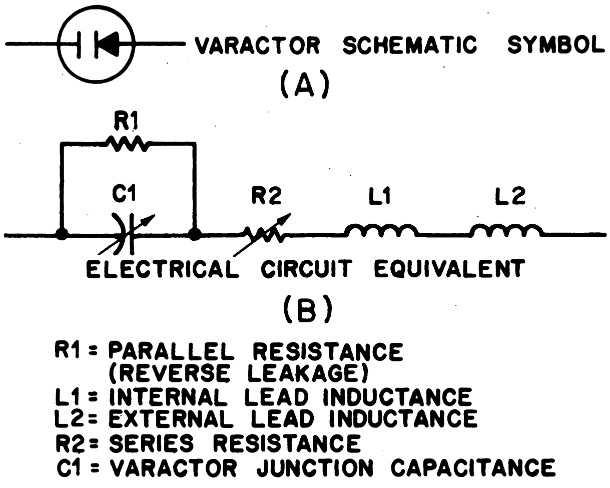
Figure 7-13.—Balanced mixer fields.

LOCAL OSCILLATOR

For years, the local oscillator used in practically all microwave radar systems was the reflex klystron. With the advent of solid state devices and particularly the varactor, it became possible to design more efficient oscillator circuits. Most modern radars today use solid state, variable frequency, voltage controlled, varactor oscillators.

As explained in *Basic Electronics*, Volume 1, NAVPERS 10087 (Series), the varactor diode is a semiconductor device that is employed as a


VARACTOR SCHEMATIC SYMBOL
(A)
R1
C1
R2
L1
L2
ELECTRICAL CIRCUIT EQUIVALENT
(B)
R1 = PARALLEL RESISTANCE (REVERSE LEAKAGE)
L1 = INTERNAL LEAD INDUCTANCE
L2= EXTERNAL LEAD INDUCTANCE
R2= SERIES RESISTANCE
C1 = VARACTOR JUNCTION CAPACITANCE

222.539

Figure 7-14.—Equivalent circuit for a varactor diode at microwave frequencies.

variable reactance circuit element, with the variable reactance being provided by the P-N junction capacitance, which varies as a function of the voltage applied to it. The varactor operates principally between a very small positive bias and the reverse breakdown voltage. Under these conditions, the varactor shown in figure 7-14(A) can be represented electrically by the equivalent circuit shown in figure 7-14(B). The fact that the junction capacitance can be varied by an applied voltage, and varied sufficiently to provide a useful capacitance change, enables the varactor diode to be used for tuning oscillator tank circuits over a wide frequency range.

Theory of Operation

Figure 7-15 is a diagram of a typical varactor, voltage-controlled, variable-frequency oscillator circuit, used in present radars. The input sawtooth voltage (developed by an automatic frequency control (AFC) circuit, which will be discussed later in this chapter) is applied across R7 to varactor diode CR1. CR1 is essentially a voltage-sensitive variable capacitor, in series with a semiconductor diode. The diode portion of CR1 is effectively at RF ground, since it is connected to the – 12 V bias line and bypassed to ground by capacitor C5. The incoming sawtooth voltage changes the capacity of CR1 P-N junction, which is in parallel with coil L4, forming a resonant tank circuit in the collector circuit of oscillator Q1. Coil L4 is effectively connected from the collector to the base of Q1, due to bypass capacitor C4. The feedback necessary to sustain oscillations is provided by adjustable capacitor C9. Taking into account the RF effects of bypass capacitors C4 and C5 (they effectively place the base of Q1, L4 and CR1 to ground or a common tie), you will note that Q1, CR1, and L4 form a transistor Colpitts oscillator circuit (which was explained in *Basic Electronics*, Volume 1).

The sine wave output signal of Q1 (whose frequency is dependent upon the capacitance of CR1) is applied to the base of Q2. Q2 is a buffer amplifier, whose output is coupled by capacitor C1 to the microwave balanced mixer local oscillator input probe.

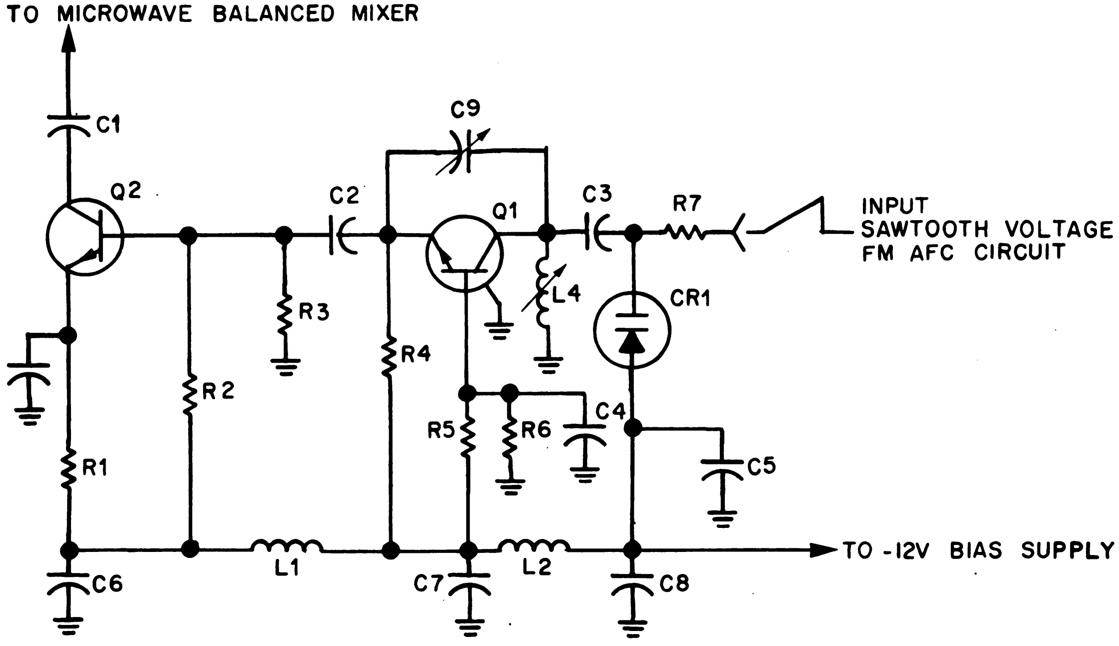


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Figure 7-15.—Typical radar varactor, voltage-controlled oscillator (VCO) circuit.

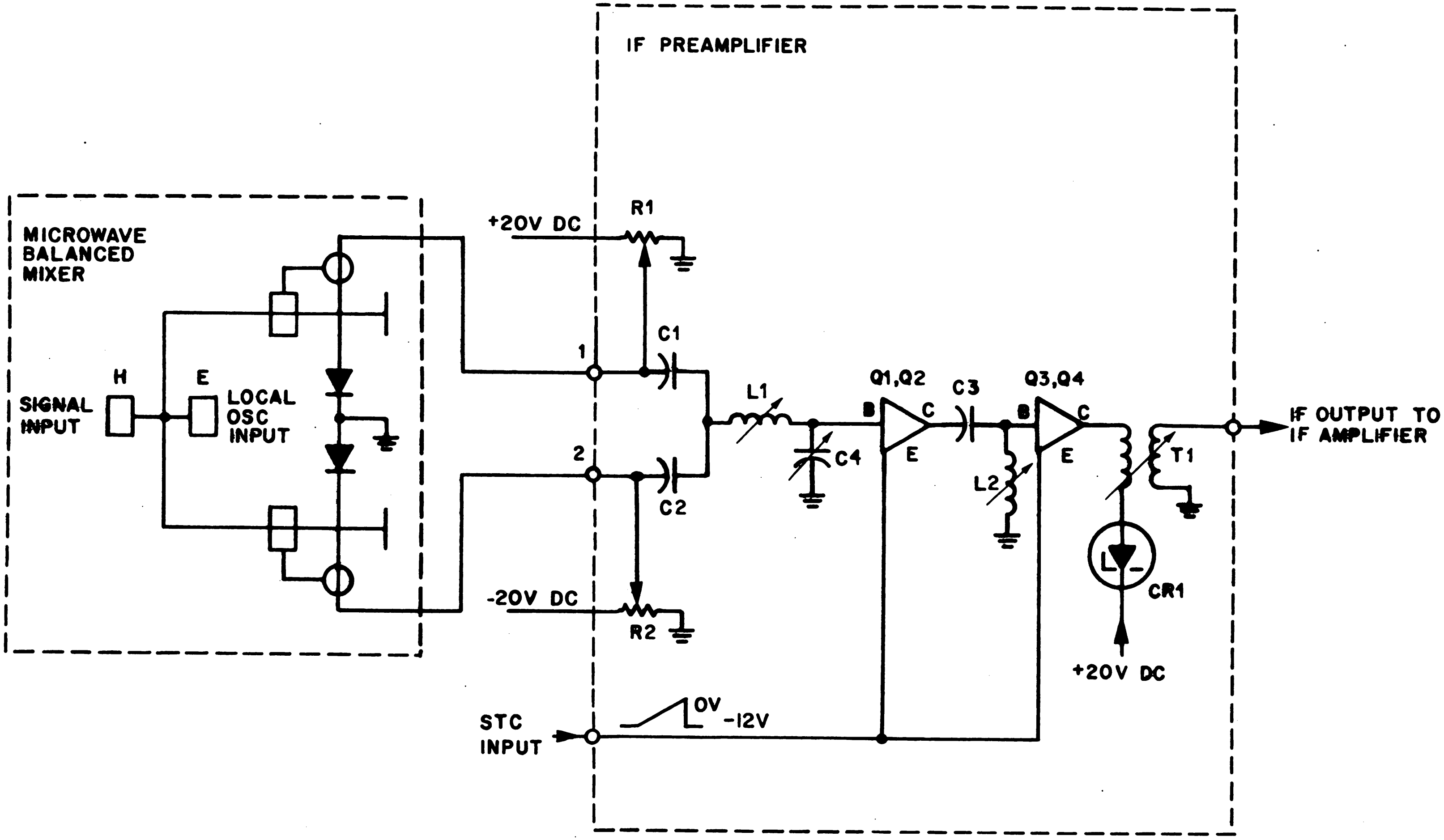

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Figure 7-16.—Typical IF preamplifier functional signal flow diagram.

IF PREAMPLIFIER

The typical radar IF preamplifier is a low-noise, high-gain amplifier, which is tuned to the receiver's IF frequency (normally in the range of 60 MHz). Figure 7-16 is a functional signal flow diagram of a typical IF preamplifier, showing its connection to a microwave balanced mixer. Figure 7-17 is a simplified schematic of the IF preamplifier with only those components labeled which appear in figure 7-16. Refer to these figures during the following discussion.

The input from the balanced mixer (received signal at the IF frequency) is coupled across C1 and C2, through L1 to the base of Q1. R1 and R2 adjust the bias of the balanced mixer crystals at the best noise figure. L1 and C4 form an impedance matching network which is also adjusted for the best noise figure. Q1 and Q2 are a high gain, cascode amplifier. The output of Q2 is taken off the collector, coupled across C3 to the bases of Q3 and Q4. Q3 and Q4 are parallel amplifiers which provide the necessary signal power without gain compression. L2 tunes the center frequency of the amplifier and T1 adjusts the amplifier's bandwidth and gain figure. The output signal is coupled across T1 and is the input to the receiver's IF amplifier stages. The rest of the unlabeled components establish biasing, and the like, for the amplifier. The STC (sensitivity time control) input controls the gain of the preamplifier to prevent saturation of the display indicator by large nearby ground clutter targets. This input is a negative going ramp voltage from an STC circuit, consisting of a monostable multivibrator, a charging RC network and a driver amplifier. The resistance of the RC network is controlled by an adjustable pot located on the radar's control panel, which the operator adjusts for best picture. By adjusting the RC time, both the ramp duration and amplitude can be set, which lowers the gain of the preamplifier for a period of the receive time. This period is usually from 0 to 20 miles on the

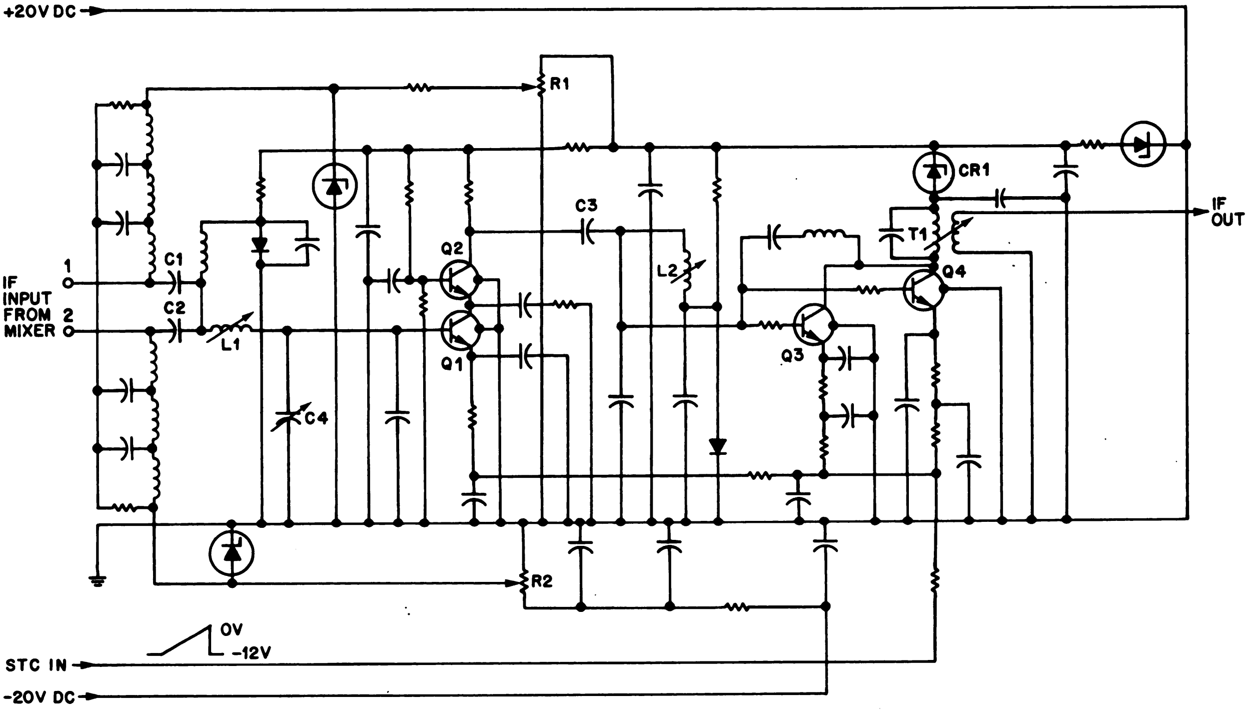

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Figure 7-17.—Typical IF preamplifier simplified schematic.

indicator. This voltage is applied to the emitters of Q1, Q3, and Q4 and controls the gain of these stages by controlling the emitter-base bias. The more STC adjusted in by the operator, the less negative voltage is applied to the emitters during STC time, thus decreasing the amplification factor.

IF AMPLIFIERS

At this point you might want to review microwave receivers in *Basic Electronics*, Volume 2, as an aid to your understanding of IF amplifier operation. Radar receiver IF amplifiers require high gain to amplify the input signal to the level required to operate the detector. Many different circuit arrangements are used to achieve this required gain. One circuit arrangement, which is increasing in use, is the logarithmic amplifier. This type of amplifier stage produces high gain while maintaining the resonant frequency and bandpass of the tuned coupling circuits fairly constant over the dynamic range of the input signal. The output of a logarithmic amplifier is a logarithmic (as opposed to linear) function of its input signal.

Figure 7-18 is a functional signal flow diagram of a typical logarithmic IF amplifier. Figure 7-19 is a schematic diagram of the first IF amplifier stage shown in figure 7-18. All of the IF amplifier stages (1st through 5th) are identical. Refer to figures 7-18 and 7-19 during the following discussion.

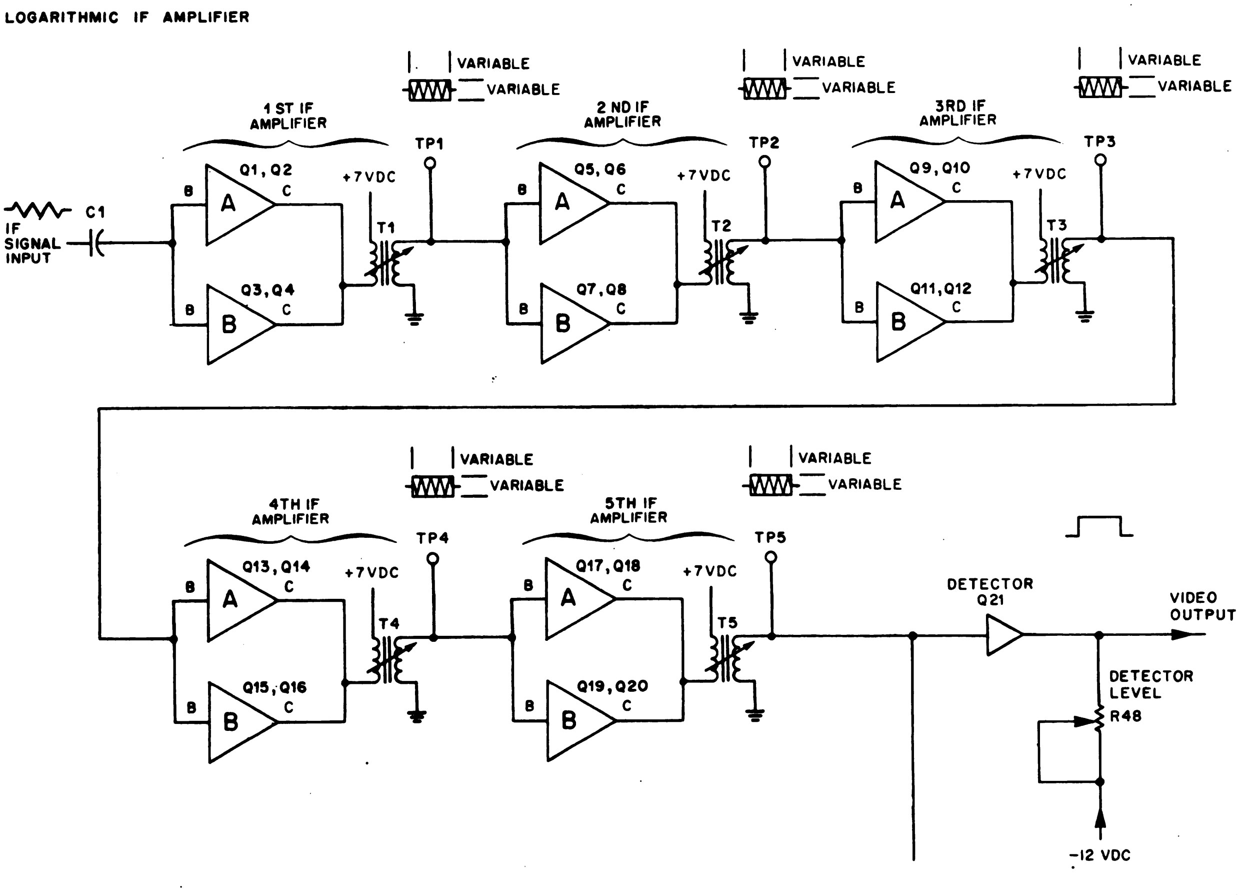

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Figure 7-18.—Logarithmic IF amplifier functional signal flow diagram.

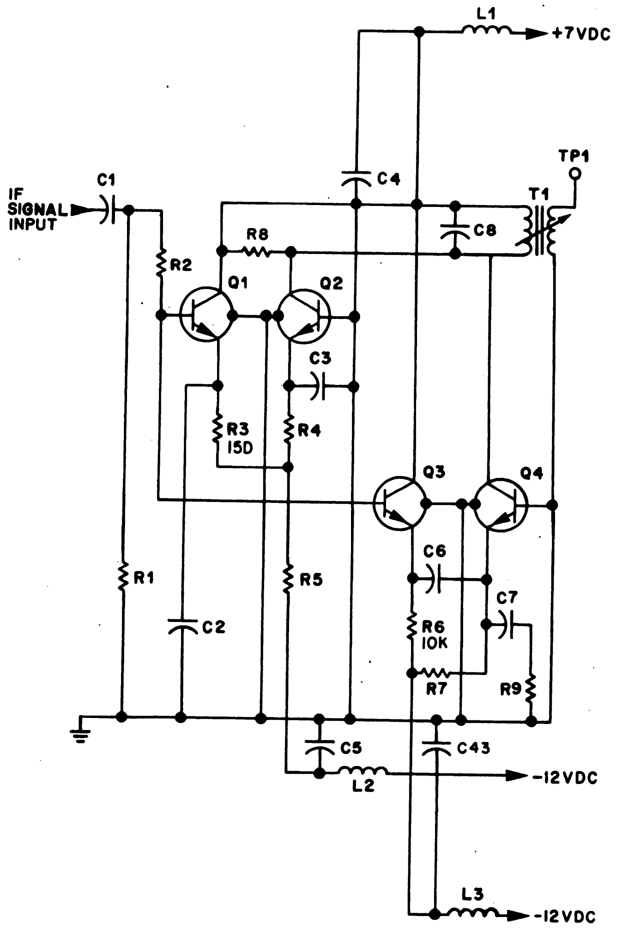

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Figure 7-19.—Typical IF logarithmic amplifier stage schematic diagram.

The IF input signal (from the IF preamplifier) s coupled across C1 to the bases of the A and B amplifiers. These amplifiers are in parallel across the output coupling transformers. The A amplifier consists of Q1 and Q2 and the B amplifier consists of Q3 and Q4. Both the A and B amplifiers are single-ended differential amplifiers.

The A amplifier (Q1 and Q2) has a constant gain of approximate unity as determined by R3 and R4. Since there is no load resistor for Q1, the ollector bias supply filter capacitor (located in he +7 V dc power supply) effectively grounds he collector for ac signals. The output of Q1 is taken off its emitter and applied through R3 and R4 to the emitter of Q2. The output of Q2 is taken off its collector and applied to T1, the interstage transformer coupler. T1 and C8 form a tuned tank, which is tuned to the IF frequency.

The B amplifier (which is in parallel with the A amplifier) has a high gain for weak signals, but is quickly limited as the input signal strength increases. When Q3 conducts (in the same manner as Q1), the output signal is taken off its emitter at the top of R6. The signal is coupled across C6 to the emitter of Q4. Q4 is so biased, that it will cut off before Q3 reaches saturation. The weaker the input signal, the more Q4 will conduct and aid the output of Q2. The output of Q4 is taken off its collector and is applied to T1 along with the output of Q2. Since Q2 and Q4 are in parallel, feeding a common load, as the input signal increases, the high-gain stage quickly decreases toward unity. This closely approximates a logarithmic response. By cascading amplifiers (1st through 5th) a large dynamic input range is attained. The output is detected after the last (5th) stage and goes to the video amplifier stages.

AUTOMATIC FREQUENCY CONTROL (AFC) CIRCUITS

The purpose of the radar receiver's AFC circuits is to tune the receiver local oscillator to the correct operating frequency. In order for the receiver to process the received signal, the local oscillator must be tuned to the proper frequency so that the IF frequency output of the receiver's balanced mixer (difference frequency of the local oscillator and received signal) is correct. To ensure this, the local oscillator must be tuned during transmit time (prior to the reception of a return pulse). To accomplish this, the AFC circuits utilize another microwave balanced mixer similar to the receiver's balanced mixer in figure 7-12(B). The inputs to this mixer are the receiver local oscillator and an attenuated sampled transmitted pulse. The output IF frequency would be the same as the receiver balanced mixer. (The received signal is the transmitter pulse reflected off a target.) The output of the AFC microwave balanced mixer goes to the receiver's AFC circuits.

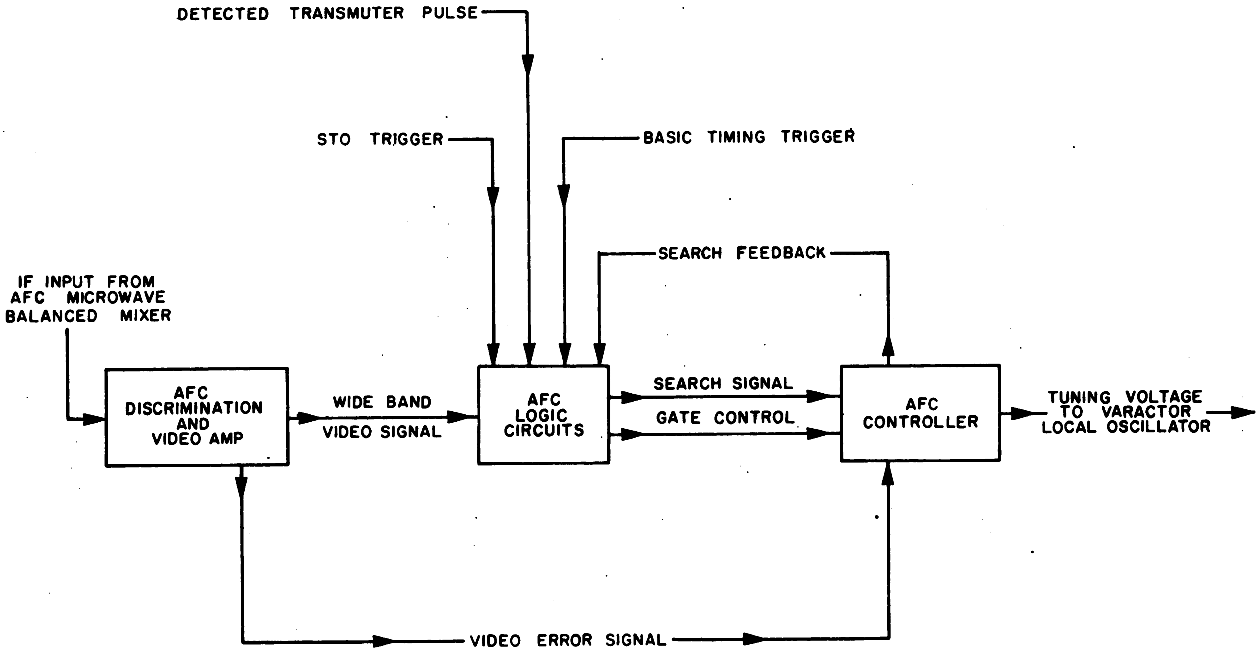

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Figure 7-20.—AFC circuit simplified block diagram.

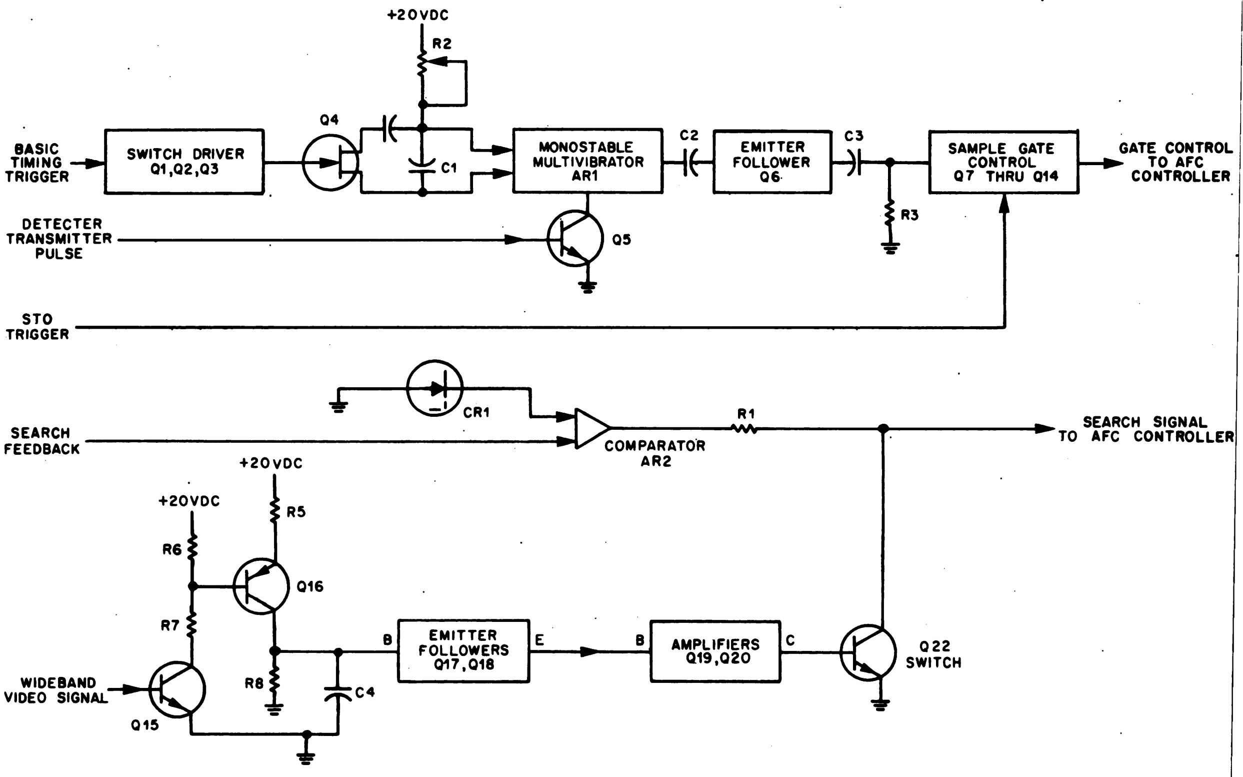

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Figure 7-21.—AFC logic circuit functional signal flow diagram.

Figure 7-20 is a simplified block diagram of a typical AFC circuit. Refer to this figure during the following discussion.

There are three basic steps or modes of operation utilized by the AFC circuits to tune the local oscillator to the correct frequency. They are referred to as "search," "acquisition," and "loop control" modes.

Search Mode

The AFC circuits go into a search mode any time the local oscillator is so far off frequency that the IF frequency produced by the balanced mixer (difference frequency of local oscillator and transmitter frequency) is outside the limits of the receiver's IF tuned circuits and cannot be processed. An IF preamplifier contained in the AFC discriminator is tuned to the receiver's IF frequency. Therefore, if the IF input to the discriminator is beyond the receiver's bandpass limits (usually plus or minus 10 MHz), the signal will not be processed by the AFC discriminator. When this occurs, there are no output signals out of the discriminator to either the AFC logic circuits or the AFC controller circuits. Instead, a comparator (fig. 7-21) AR2 part of (p/o) the AFC logic circuit gets an input (search feedback) from an integrator (fig. 7-22) AR2 p/o the AFC controller circuit. This input may be either positive or negative depending on the output state of the integrator. The output of the comparator (fig. 7-21) is coupled through R1, bypasses switch Q22 (which is cut off as there is no wideband video signal input from the discriminator), and goes to CR1 and CR3 (fig. 7-22) of the AFC controller. Depending on the polarity of the comparator output, the output goes through either CR1 and CR2, or CR3 and R1, to the integrator AR2. The gain of the integrator is different for the different polarities of the comparator output. This results in a sawtooth output voltage from the integrator AR2. The sawtooth voltage goes through the summing amplifier AR3 and is also fed back to the comparator AR2 (fig. 7-21), which causes it to change states when a certain voltage level is reached. The output of the summing amplifier AR3 is applied to the sample gate Q2 (N-channel

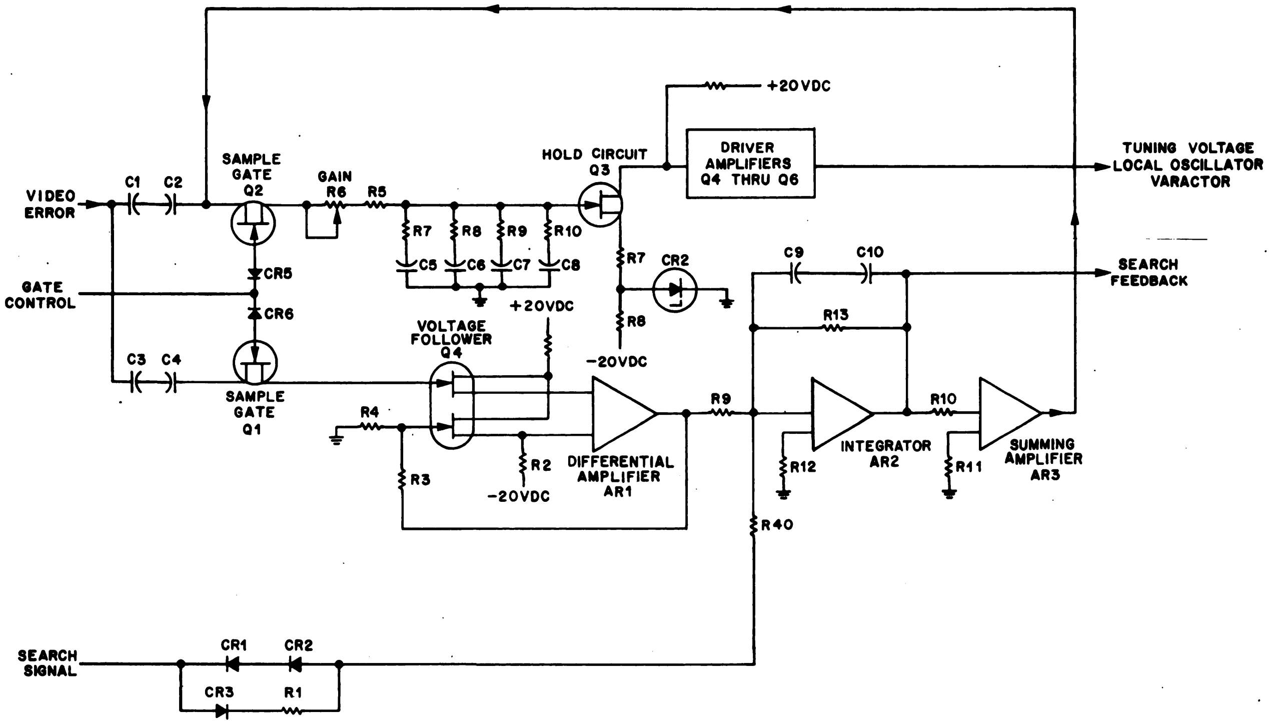

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Figure 7-22.—AFC controller functional signal flow diagram.

JFET). The gate Q2 is open at this time. (This will be explained when we cover the sample gate control p/o the AFC logic circuit.) The sawtooth goes through Q2, across a hold charging circuit consisting of R7, 8, 9, and 10; and C5, 6, 7, and 8, through gate Q3, is amplified by drivers Q4 through Q6 and is applied to the receiver local oscillator varactor. The amplitude of the sawtooth will cause the local oscillator to sweep through its entire operating range. It is also large enough to overcome the hold circuit.

When the local oscillator reaches a frequency where, when it is mixed with the sampled transmitted pulse in the microwave mixer, and an IF frequency is produced within the IF bandpass of the receiver (± 10 MHz), the IF signal will be processed by the AFC discriminator circuits. At this point, acquisition has occurred.

Acquisition Mode

Once the AFC mixer's IF frequency output is within the ±10 MHz bandpass of the AFC discriminator's preamplifier, the input to the discriminator (fig. 7-23) will be amplified/limited (depending on signal amplitude) by Q1 through Q3. The output of Q3 is fed via Q4 to the discriminator circuit consisting of T1, R4, R5, R6, C1, C2, R7, R8, R9, CR1, CR2, C3, and C4. The output of Q3 is also fed to Q6. The circuitry of Q6 phase shifts the output (delays the signal) by 270°. The output of Q6 is applied between CR1 and CR2 and is the reference signal for the discriminator. The output of Q6 is also applied to wideband filter Q12 and Q13.

The operation of the discriminator is similar to the Foster-Seeley discriminator explained in *Basic Electronics*, Volume 1. It is basically a phase detector with the output rectified and filtered. The output of the discriminator is a pulse, the width of the transmitter pulse, that has an amplitude and polarity which is determined by the frequency difference between the local oscillator and the sampled transmit pulse. This output is amplified by Q7 through Q11 and is the video error signal, which is applied to C1 and C3 (fig. 7-22) of the AFC controller.

The output of the wideband filter Q12 and Q13 (fig. 7-23) is detected by Q14, amplified by

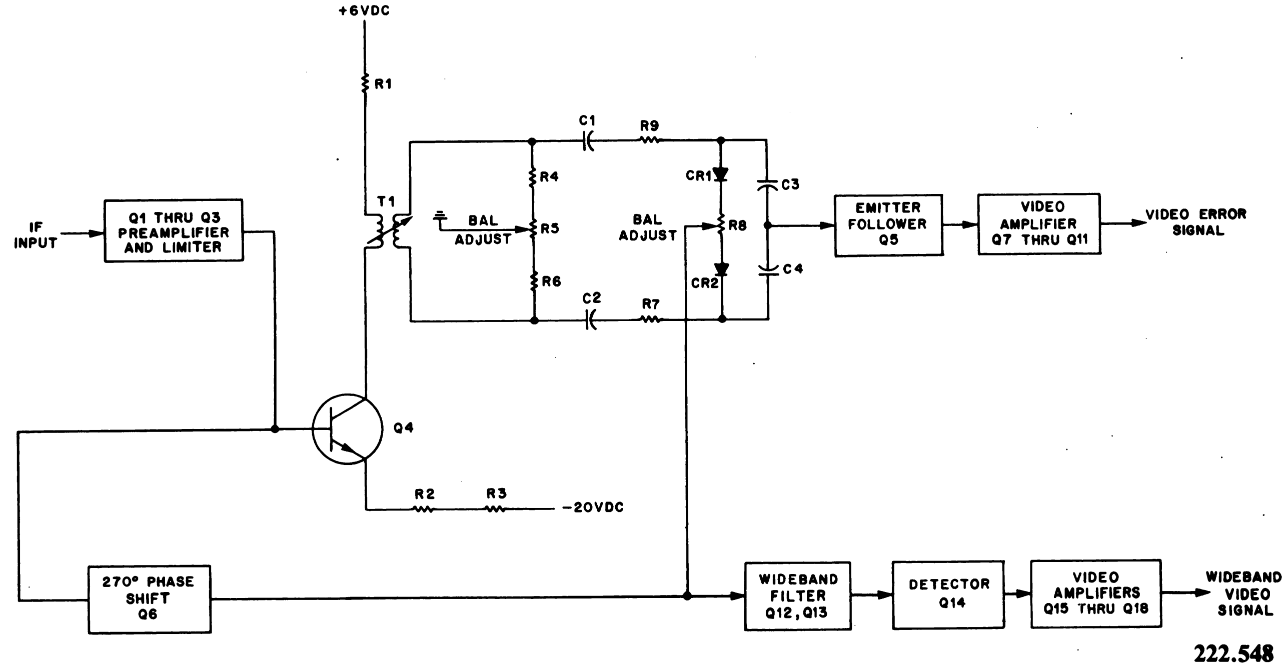

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Figure 7-23.—AFC discriminator and video amplifier functional signal flow diagram.

Q15 through Q18, and is the wideband video signal, which is applied to Q15 (fig. 7-21) of the AFC logic circuit.

The wideband video signal causes Q15 and Q16 to conduct, which charges C4. When the charge on C4 reaches a predetermined value, the signal is coupled by Q17 and Q18 to amplifiers Q19 and Q20, and turns on switch Q22. Q22 clamps the output of the comparator AR2, and also clamps the feedback circuit (fig. 7-22) of the integrator AR2 p/o the AFC controller. The integrator will no longer generate the (search) sawtooth voltage to the local oscillator. At this point, the search mode is terminated, acquisition is complete, and tracking (loop-control mode) begins.

Loop-Control Mode

There are actually two paths or loops comprising the loop-control mode. One is commonly referred to as "slow loop," which corrects the oscillator frequency from ± 10 MHz to within ±5 MHz of the desired IF center frequency. The second path is referred to as the "fast loop" and will correct the oscillator frequency from ±5 MHz to the correct frequency.

SLOW-LOOP OPERATION.—The video error signal (fig. 7-22) which was the output of the discriminator (beginning at acquisition) is applied to C1 and C3. C1 is the fast-loop circuit, which is ineffective when the local oscillator frequency error exceeds ±5 MHz. (We'll see why shortly.) The video error signal is coupled across C3 and C4 to sample gate Q1. Q1, just as Q2 in search, is open at this time. (We'll explain how when we discuss the sample gate control later in this chapter.) The signal passes through gate Q1 to Q4. Q4 and AR1 operate as a voltage follower circuit. The output of AR1 is integrated by AR2, amplified by AR3, and applied across the opened sample gate Q2 to the hold circuit. Slow-loop operation can be summarized as follows: So long as the oscillator frequency error exceeds ±5 MHz, then the slow-loop circuit takes a series of video error signal samples, and integrates them until a sufficient voltage level is reached to charge the hold circuit to open gate Q3 and drive the local oscillator frequency to within ±5 MHz of the desired frequency. Once this is accomplished, fast-loop operation begins.

FAST-LOOP OPERATION.—The video error-signal output of the discriminator will now be coupled across C1 and C2 to the sample gate Q2. The sample gate at this time will open periodically as determined by the sample gate control circuits p/o the AFC logic circuit. When gate Q2 opens, the video error signal goes to the hold circuit of Q3. The hold circuit, which was charged by the slow-loop circuits, is at the threshold voltage level to turn on Q3. The error signal amplitude is sufficient to turn on Q3 and send a short voltage burst to the local oscillator varactor to tune the oscillator to the desired frequency. Once the desired frequency is reached, there will no longer be a video error-signal output from the discriminator and no further tuning of the local oscillator. Should the transmitter frequency or local oscillator frequency drift slightly, a video error-signal output from the discriminator would again go through the fast loop circuits and retune the local oscillator. In this manner the AFC circuits maintain the desired IF frequency output of the receiver's balanced mixer.

Sample Gating Operation

The sample gates, Q1 and Q2 (fig. 7-22), are initially opened by an STO trigger (fig. 7-21) being applied to the sample gate control circuits Q7 through Q14. Prior to receiving the STO trigger, the output of Q14 is a highly negative (approximately − 15 V dc) voltage, which, applied across (fig. 7-22) CR5 and CR6, causes the N-channel gate to be closed. The STO trigger is a pulse from the radar synchronizer and occurs a few microseconds prior to the basic timing pulse, which fires the transmitter and the scope sweep circuits, etc. This ensures the sample gate is opened prior to any possible output from the receiver or AFC balanced mixers. (The output of the balanced mixers is the difference frequency of the local oscillator and sampled transmitter pulse.) The gates Q1 and Q2 (fig. 7-22) will close (fig. 7-21) with the detected transmit pulse being applied to Q5. This pulse triggers a monostable multivibrator, AR1. The negative pulse output of AR1 causes the sample gate control Q7 through Q14 to turn off (close) the sample gates Q1 and

Q2 (fig. 7-22). The multivibrator will generate different negative output pulses depending on the PRF of the radar. Since a typical radar is normally capable of operating at two different PRF's and pulse widths for long- and short-range operation, the basic timing pulse (fig. 7-21) is applied to switch drivers Q1 through Q3. The output of the switch drivers opens and closes gate Q4, which changes (determines) the time constant of AR1. Therefore, sample gates Q1 and Q2 (fig. 7-22) will be open for different periods of time depending on the PRF of the radar. However, the overall time the sample gates are opened is from the STO trigger time to the time of the detected transmitter pulse. The time constant of the monostable multivibrator is such that gates Q1 and Q2 (fig. 7-22) will close just prior to the trailing edge of the transmitted pulse. This is to ensure that the AFC circuits will not inadvertently tune the receiver local oscillator during the receive cycle of the radar operation.

SPECIAL RECEIVER CIRCUITS

Gain control of radar IF amplifiers takes many different forms. The simplest type is manual gain control. More complex forms of gain control are automatic gain control (AGC), instantaneous automatic gain control (IAGC), and sensitivity time control (STC). Gain control is necessary to adjust the radar-receiver sensitivity for signals of widely varying amplitude. Some gain-control circuits are used to overcome either unintentional interference or intentional interference (jamming).

Although it is possible to control IF gain with only one IF amplifier stage, the amount of control is usually insufficient. Because a stage has capacitance between its input and output ends, a signal is coupled to the output end even when the stage is cut off. The maximum variation in gain by the control of a single stage is approximately 20 db. With two-stage gain control, approximately 40 db of gain variation can be obtained.

Automatic Gain Control

Many radar sets are provided with AGC as well as manual gain control. Provision is usually made for switching between automatic and manual gain control. In this way, manual gain control can be used, if necessary, to adjust for best reception of a particular signal.

The various types of gain control differs in the following ways:

1. Circuits used.
2. Speed of response.
3. Type of response.

The simplest type of AGC adjusts the IF amplifier bias (and gain) according to the average level of the receiver signal. AGC is not used as frequently as other types of gain control because of the widely varying amplitudes of radar return signals.

With AGC, gain is controlled by the largest received signals. When several radar signals are being received simultaneously, the weakest signal may be of greatest interest. IAGC is used more frequently because it adjusts receiver gain for each signal.

INSTANTANEOUS AUTOMATIC GAIN CONTROL

A typical IAGC circuit is essentially a wide-band, dc amplifier that instantaneously controls the gain of the IF amplifier as the radar return signal changes in amplitude. This is accomplished by using an output of the second detector of the receiver as bias for the amplifier. The effect of IAGC is to decrease the amplification of strong signals and to allow full amplification of weak signals. The range of IAGC is limited, however, by the number of IF stages in which gain is controlled. This is the reason most modern receivers use sensitivity time control.

Sensitivity Time Control

In radar receivers, the wide variations in return signal amplitude make adjustment of the radar-receiver gain difficult. The adjustment of receiver gain for best visibility of nearby target return signals. Circuits used to adjust amplifier gain with time, during a single pulse repetition period, are called STC circuits.

Figure 7-24 shows a schematic diagram and output-voltage waveform of an STC circuit. The input signal to the STC circuit (fig. 7-24(A)), is

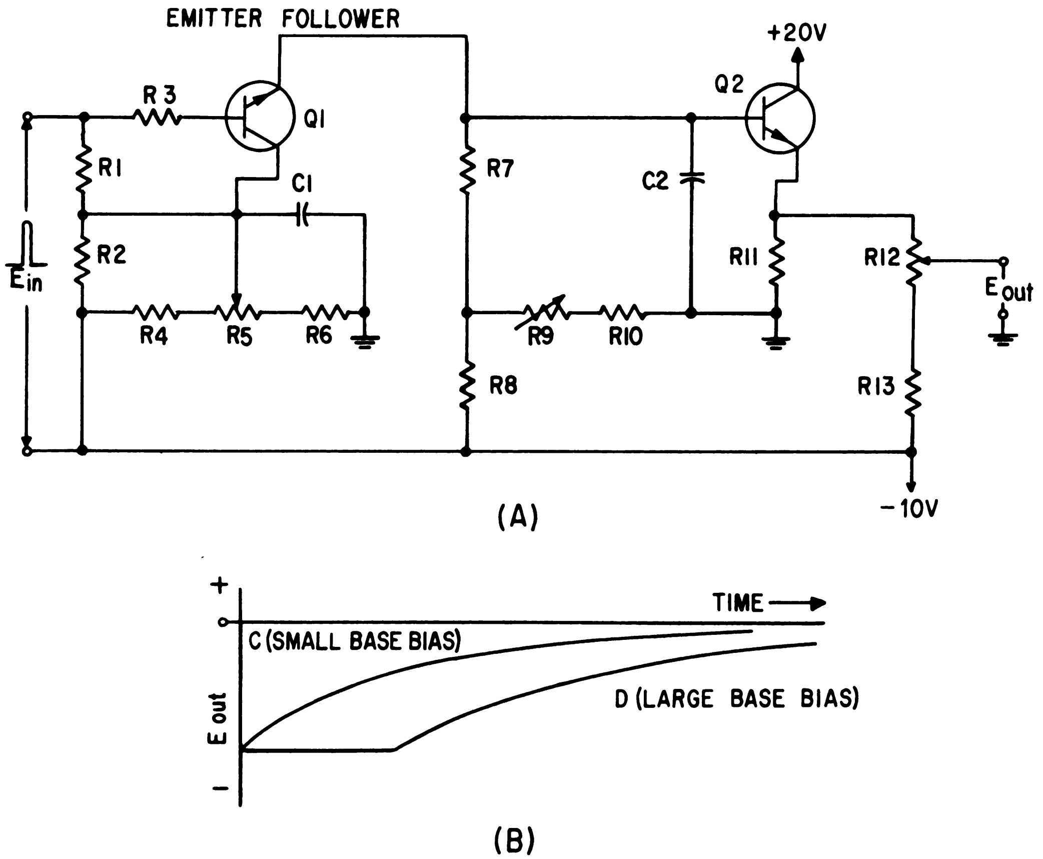

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Figure 7-24.—Sensitivity time cntrol circuit. (A) Schematic diagram; (B) waveform of output voltage.

a pulse obtained from the radar modulator. When the modulator pulse is applied to the base of emitter follower Q1, a large voltage appears across capacitor C1. At the same time, a negative voltage appears across capacitor C2. The amount of negative bias developed across capacitor C2 is determined by the setting of potentiometer R5. A large voltage across C2 drives Q2 beyond cutoff. Thus, E_{out} (curve D, fig. 7-24(B)) remains constant while the voltage across C2 decays toward zero. When the voltage across C2 becomes equal to the Q2 cutoff voltage, Q2 begins to conduct and E_{out} rises toward zero.

Output voltage E_{out} (fig. 7-24(A)) is applied to the base of an IF amplifier (not shown) and thus places a constant bias on the IF amplifier for a short time after the modulator pulse. During this period, the IF amplifier gain is held constant. When the Q2 output voltage begins to decrease, less bias is applied to the IF amplifier, and the receiver sensitivity increases with time. As a result, weak signals from distant targets are amplified more than signals from nearby targets.

If potentiometer R5 is set so that Q1 is not driven beyond cutoff, the bias on Q2 begins to decrease as soon as the modulator pulse ends. In this case, output voltage E_{out} rises toward zero, as shown by curve C (fig. 7-24(B)). As a result, a large negative bias is applied to the IF amplifier at the time of the modulator pulse, thereby decreasing IF amplifier gain.

As soon as the modulator pulse ends, the bias applied to the IF amplifier begins to decrease, and IF amplification begins to increase. Thus, the IF amplifier gain is minimum directly after a modulator pulse. Also, the gain increases at a later time, when weak signals from distant targets are expected.

The combination of STC and IAGC circuits results in better overall performance with either type of gain control alone. STC decreases the amplitude of nearby target return signals, while IAGC decreases the amplitude of larger-than-average return signals. Thus, normal changes of signal amplitudes are adequately compensated by the combination of IAGC and STC.

In some cases very large changes of signal amplitude are encountered. For example, enemy jamming may produce large amplitude interfering signals. The interfering signals may be either continuous or pulsed. The interfering-signal amplitudes may be large enough to block the receiver, and thus cover up signal return from enemy aircraft. To overcome jamming, special receiver circuits, called antijamming circuits, are used.

Antijamming Circuits

Among the many different circuits used to overcome the effects of jamming, two important ones are gated AGC circuits, and short-time-constant circuits. A gated AGC circuit permits signals that occur only in a very short time interval to develop AGC. If large amplitude pulses from a jamming transmitter arrive at the radar receiver at any time other than during the gating period, the AGC does not respond to these jamming pulses.

Without gated AGC, a large received signal from a jamming transmitter would cause the automatic gain control to follow the interfering signal and to decrease the desired signal amplitude to an unusable value. Because gated AGC produces an output signal for only short times, the AGC output voltage must be averaged over several cycles to keep the automatic gain control from becoming unstable.

Although gated AGC does not respond to signals that arrive at times other than during the desired-target return signals, AGC can do nothing with interference that occurs during the gating period. Neither can gating the AGC prevent the receiver from overloading due to jamming signal amplitudes far in excess of the desired-target return signal of that particular amplitude. As an aid in preventing radar-receiver circuits from overloading during the reception of jamming signals, short-time-constant coupling circuits are used to connect the video-detector output to the video-amplifier input circuit.

A short time constant or a fast time constant (FTC) circuit is a differentiator circuit located at the input of the first video amplifier. When a large block of video is applied to the FTC circuit, only the leading edge will pass due to the short time constant of the differentiator. A small target will produce the same length of signal on the indicator as a large target, because only the leading edge is displayed. The FTC circuit has no effect on receiver gain; and although it does not eliminate jamming signals, it greatly reduces them.

VIDEO AMPLIFIERS

Video amplifiers are used to amplify the output signal from the video detector to a level high enough to be used by the radar presentation system. Because radar receivers are frequently far removed from the presentation circuits, some video amplification is provided in the radar receivers. Video amplifiers may also be located in the radar presentation circuits (scope).

Since the radar video signal may have frequency components up to several MHz, coaxial cables are used to connect the video output circuit of the receiver to the video input circuit of the presentation system. When these coaxial cables are long, special video-amplifier circuits are generally used in the radar receiver.

Among the video-amplifier problems which must be met in radar circuits are as follows:

1. Limitation of low-frequency response. (This limitation occurs when cathode-bypass capacitors are used.)
2. Limitation of low-frequency response by screen-grid bypass capacitance (capacitance between the screen grid and ground).
3. Limitation of high-frequency response by input interelectrode capacitance, distributed wiring capacitance, and output interelectrode capacitance.

Some of the special video-amplifier circuits mentioned above, whose purpose is to compensate for these problems, are discussed in *Basic Electronics*.

The high frequency performance of solid-state circuits, has been improved greatly since the early devices, which were generally limited to about 500 kHz. They are now capable of operating at frequencies far above the operating range of conventional vacuum tubes. Transistors do have high frequency limitations, however, and the design of high frequency transistor circuits must take into account factors which are not significant at low frequencies.

Basically, these high frequency limitations arise because of transit time effects and the inherent junction capacitance. At high frequencies, these factors become significant and begin to affect the operation of the circuit. Stage gain is lowered, and problems involving instability appear as the impedance and gain of the transistor become complex quantities.

When transistors having an upper frequency limit only slightly higher than, or equal to, the high frequency end of the desired video band are used, the attenuation and phase shift due to the transistor must be compensated for in the amplifier. This may be accomplished by the use of compensating networks and/or the use of negative feedback.

Basically, the high frequency compensation of video amplifiers consists of attenuating the normal midrange gain of the amplifier to within a few db of the maximum gain obtainable at the highest frequency of interest, so that the bandwidth is extended to this high frequency. This is how negative feedback increases the bandwidth of an amplifier. It may be used around one or more stages, and it results in increased stability as well as bandwidth.

Two-terminal high frequency compensation circuits using two or more compensating elements are commonly used in vacuum tube circuits. These circuits can also be used for the high frequency compensation of transistor amplifiers, although the design relationships are not quite as straightforward. This method of high frequency compensation consists essentially of using RLC peaking circuits to maintain a nearly constant amplification factor over the required band.

The three-stage 50-MHz wide-band amplifier shown in figure 7-25(A) uses negative feedback frequency compensation in conjunction with an RLC compensating network placed directly in the feedback path. This arrangement provides 34 db of negative feedback from 50 kHz to 5 MHz.

The current amplification factor is virtually flat at 34 db from dc to 10 MHz, and within 3 db to 50 MHz. The feedback RLC network maintains the feedback loss flat to 10 MHz. The interstage RLC networks compensate the gain characteristic between 5 and 100 MHz, and the feedback around the first stage provides compensation in the vicinity of 7 MHz. The emitter bypass capacitors control the frequency response from dc up to approximately 50 kHz. The frequency characteristic of the amplifier is shown in figure 7-25(B).

Video signals are usually coupled to the presentation circuits through relatively long lengths of low-impedance, large-capacitance coaxial cables. Thus, video output stages generally have a low output impedance.

These coaxial cables may have a capacitance of 20 $\mu\mu$f per foot. Thus, a 5-foot cable would have a capacitance of 100 $\mu\mu$f. To prevent attenuation of high-frequency signals by the shunt capacitance, coaxial cables must be terminated in their characteristic impedance (usually 100 ohms or less).

For coaxial cables that are very short (less than a quarter-wavelength long), the termination resistance may be higher than the characteristic impedance without affecting high-frequency response. Higher values of terminating resistance result in higher output voltages.

RADAR INDICATORS

The various types of radar indicators (A-scope, B-scope, PPI-scope, etc.) and some of the fundamental principles of their operation are discussed in *Basic Electronics*. Review of the basic principles before continuing with the present discussion is recommended. In the following paragraphs, details of radar indicator operation which go beyond the basic level are presented.

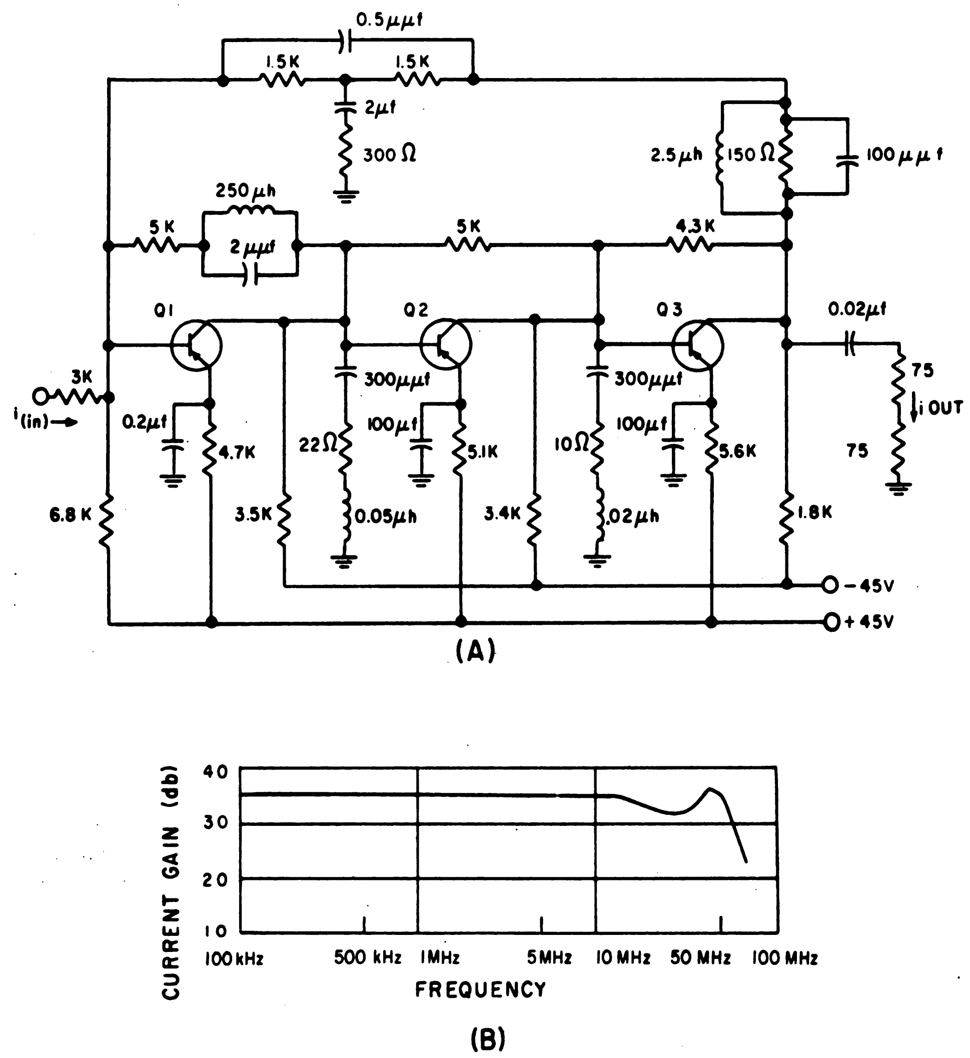

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Figure 7-25.—Three-stage 50 MHz video amplifier. (A) Circuit; (B) frequency characteristic.

A-SCOPE

Figure 7-26 is the simplified block diagram and scan presentation of a typical A-scope. Although the A-scope is not used in modern weapons systems radar, it is presented to establish a basic understanding of scopes before discussing the more advanced type. In the operation of the A-scope an initial trigger pulse from the timer is applied to both the radar transmitter and the one-shot (monostable) multivibrator in the A-scope. The one-shot multivibrator generates the following:

1. A negative gate pulse that is fed to the range marker generator.

2. A negative gate pulse that is fed to the range sweep generator.

3. A positive gate pulse that is fed to the control grid of the cathode-ray tube.

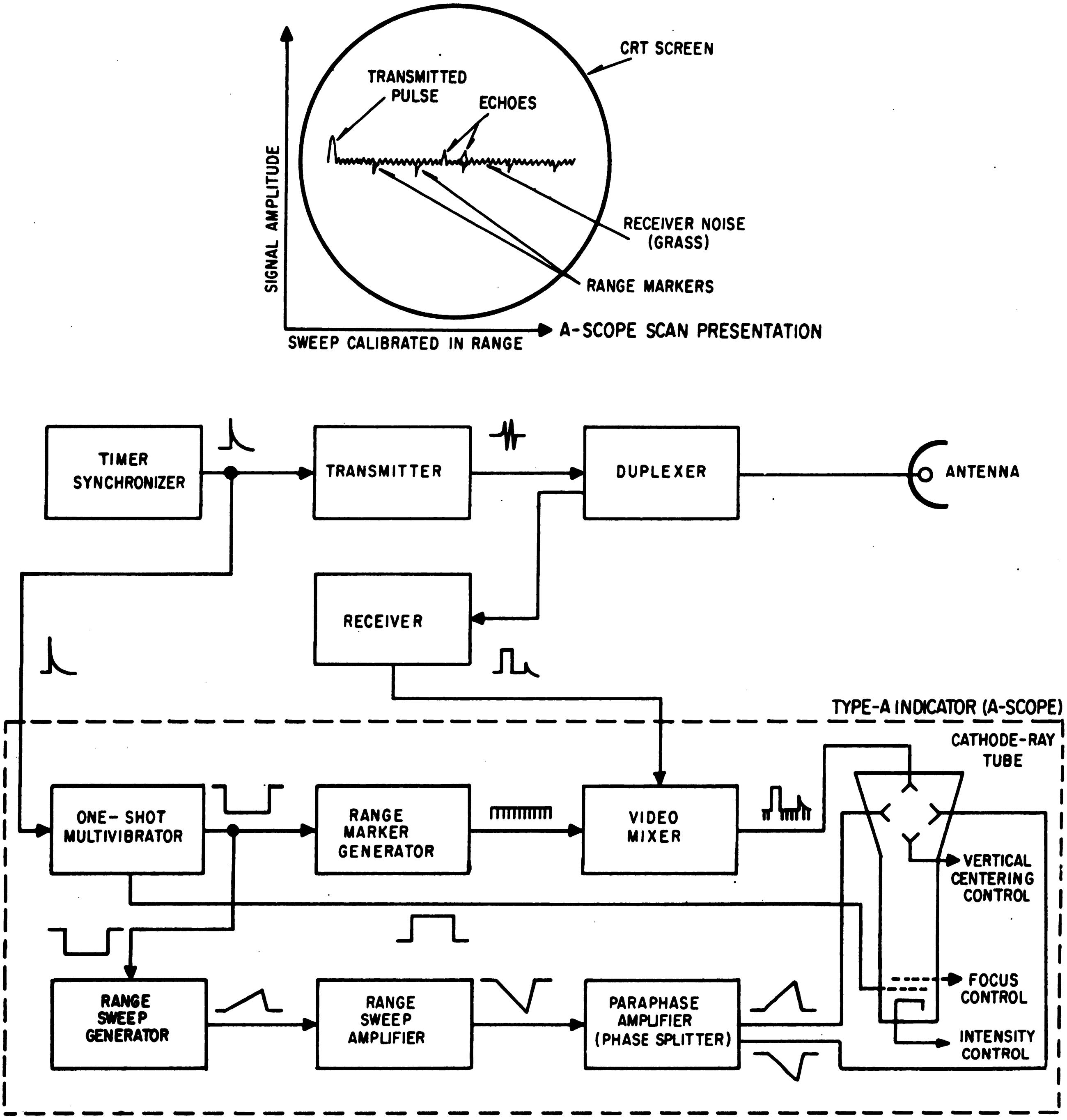

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Figure 7-26.—Typical A-scope block diagram and scan presentation.

The gate pulse to the range marker generator causes a series of equally spaced range marks to be generated. These range marks are added to the receiver output signal in the video mixer. The output of the video mixer is applied between ground and one vertical-deflection plate of the cathode-ray tube. The other vertical-deflection plate is connected to the vertical-centering control. (In some cases, the receiver output signal is applied to one vertical-deflection plate, and the range marks are applied to the other vertical-deflection plate.)

The negative gate pulse, fed to the range sweep generator, causes a nearly linear sawtooth sweep voltage to be generated. In general the different timing capacitors in the one-shot multivibrator and in the range sweep generator are connected to a common range switch. In this way, the RC time constants of both circuits are changed simultaneously when the operating range is changed.

When the duration of the negative gate pulse is changed, the duration of the sawtooth sweep voltage is changed, but the amplitude of the sweep voltage is unchanged. Hence, for different operating ranges, the scanning spot travels approximately the same distance across the A-scope screen. However, the speed of the scanning spot increases as the range setting is decreased.

The sawtooth output of the range sweep generator is amplified by the range sweep amplifier, and then applied to the paraphase amplifier (phase splitter). The paraphase amplifier permits the sawtooth sweep voltage to be applied in push-pull to the horizontal-deflection plates of the cathode-ray tube. This reduces defocusing of the electron beam, which usually results when the sweep voltage is applied to only one horizontal-deflection plate.

The positive gate pulse applied to the control grid of the cathode-ray tube intensifies the electron beam during the sweep time. This enables the output of the video mixer to be displayed on the A-scope screen. When the positive gate pulse is removed, blanking results (the electron beam is cut off).

Clamping circuits are frequently used with A-scopes to keep the display properly positioned despite changes in the average (dc) value of the sweep or signal voltages. (Remember, clampers hold one part of the signal waveform at a constant voltage level.) In some A-scopes, expanded sweep circuits are used. These circuits enable a small

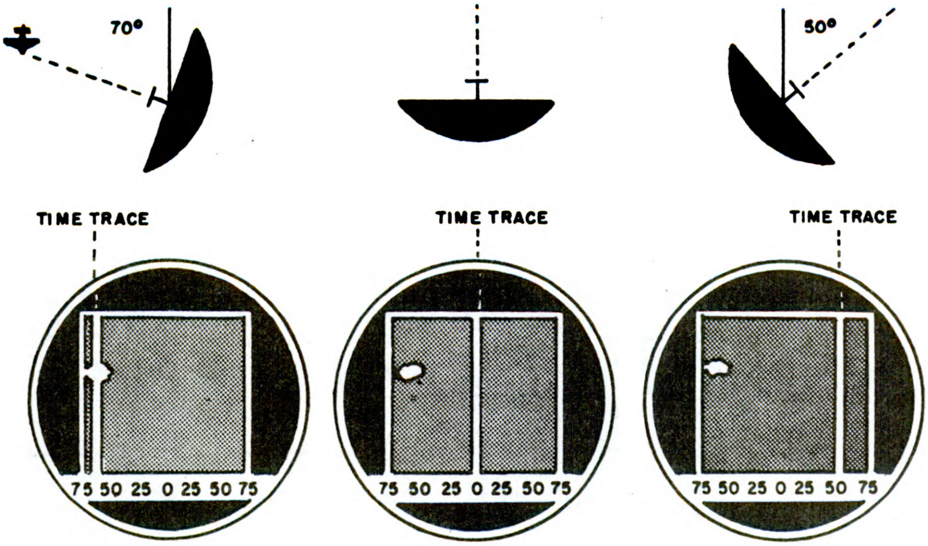

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Figure 7-27.—B-scan presentation.

section of the sweep to be expanded to cover the A-scope screen. Thus, more accurate range measurements can be made.

B-SCAN

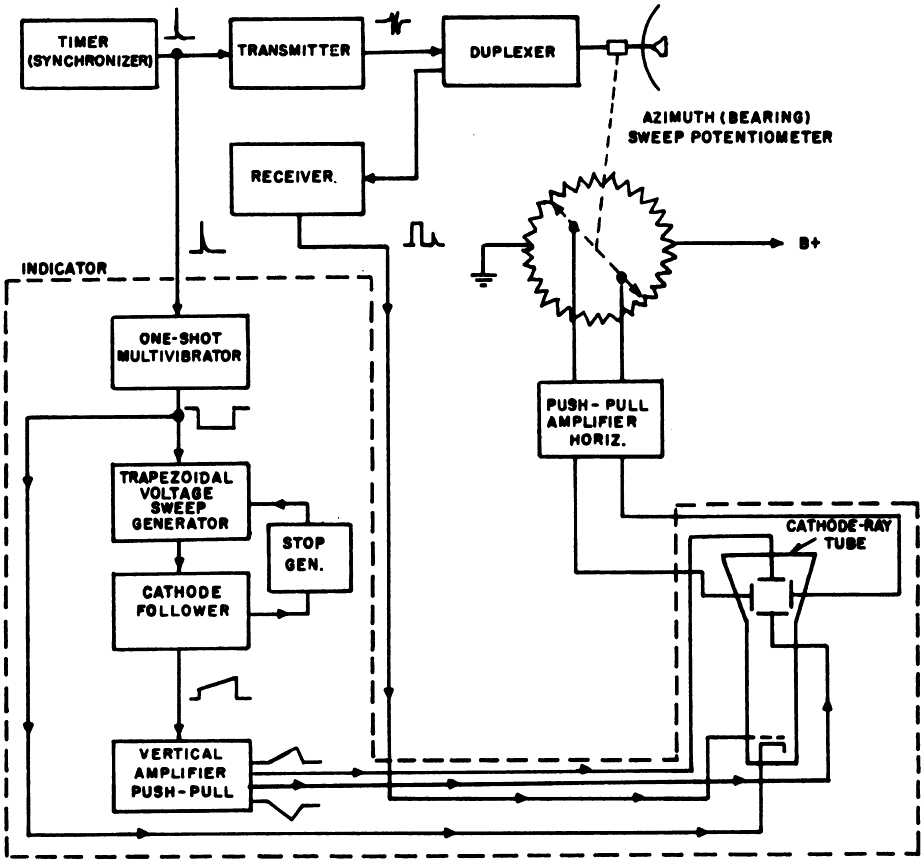
Often the situation in which a radar is used calls for simplicity of circuitry and construction; therefore, B-scan is often used.

In B-scan, three variables are possible. These are range, a function of time; azimuth, a function of antenna rotation; and the intelligence received by the radar or associated equipment.

From the operator's standpoint, the ideal situation would be the presentation of an exact replica of the area scanned. This would involve complicated construction and circuitry. The B-scan represents a compromise between the extremes of simple and complex circuitry.

B-scan involves the simplest circuitry and construction of any two-dimensional presentation and yet presents information in a reasonably faithful replica of the area scanned by the antenna (figure 7-27). It works best under conditions where the antenna scans a sector of less than 180°, but it can be employed in a situation where a 360° area is scanned.

Range is usually presented vertically by the use of a conventional sweep circuit. (Refer to the B-scope block diagram in figure 7-28.) The scope presentation may be created by either magnetic or electrostatic deflection. Since electrostatic deflection is usually employed, the final amplifiers are operated push-pull to gain the advantage of good sweep linearity.


TIMER (SYNCHRONIZER)
TRANSMITTER
DUPLEXER
AZIMUTH (BEARING) SWEEP POTENTIOMETER
RECEIVER
B+
INDICATOR
ONE-SHOT MULTIVIBRATOR
TRAPEZOIDAL VOLTAGE SWEEP GENERATOR
STOP GEN.
CATHODE FOLLOWER
PUSH-PULL AMPLIFIER HORIZ.
CATHODE-RAY TUBE
VERTICAL AMPLIFIER PUSH-PULL

222.112

Figure 7-28.—Block diagram of a B-scope system.

Azimuth is presented horizontally by the use of a potentiometer that is mechanically connected to the antenna. The output of the potentiometer controls the horizontal push-pull amplifiers which in turn controls the horizontal deflection.

The intelligence is presented on the indicator by intensity-modulating the sweep. The antenna scanning speed is approximately one scan per second, whereas the sweep speed is at the PRF rate; therefore, the intelligence will also have range and bearing.

C-SCOPE

Type-C indicators, or C-scopes (fig. 7-29) are used primarily to present data on the bearing and elevation of targets. Type-C indicators may sometimes be used in aircraft interception. Like B-scopes, C-scopes provide a rectangular display on their screens. However, in C-scopes the vertical axis represents elevation, and the horizontal axis represents bearing. Thus, in aviation fire control radar, targets may appear on either side of both the horizontal and vertical axes.

To obtain a rectangular display on the screen of a C-scope, both horizontal- and vertical-sweep generators are used. Since the sweep frequencies are relatively low, potentiometers (like the azimuth sweep potentiometer of the B-scope) are generally used. These potentiometers are connected to the radar antenna.

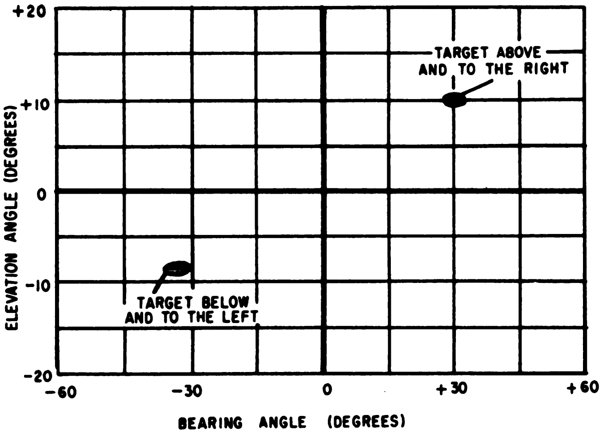


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Figure 7-29.—C-scope presentation.

When the antenna turns sideways, the scanning spot on the C-scope screen is deflected horizontally. When the antenna is tilted up or down, the scanning spot is deflected vertically. Echo signals, applied to the control grid (or cathode) of the cathode-ray tube during the sweep period, cause the brightness of portions of the horizontal trace to be increased. The position of a bright spot indicates the elevation and bearing of a target.

Targets at different ranges, but with the same bearing and elevation, appear as a single spot on a C-scope. Targets of this kind cannot be distinguished individually on the C-scope. For this reason, an indicator that presents range data is generally used in conjunction with a C-scope. Once the range of a particular target has been determined, a range gate pulse (rectangular pulse) is applied to the C-scope. This intensifies the electron beam only for the duration of the range gate pulse. Thus, only the desired target echo appears on the C-scope; all other signals are blanked out. In this way, the bearing and elevation of a particular target at a specific range can be determined.

When used in conjunction with modern aviation weapons systems radars, C-scopes will generally be used to display information obtained from an infrared (IR) detector.

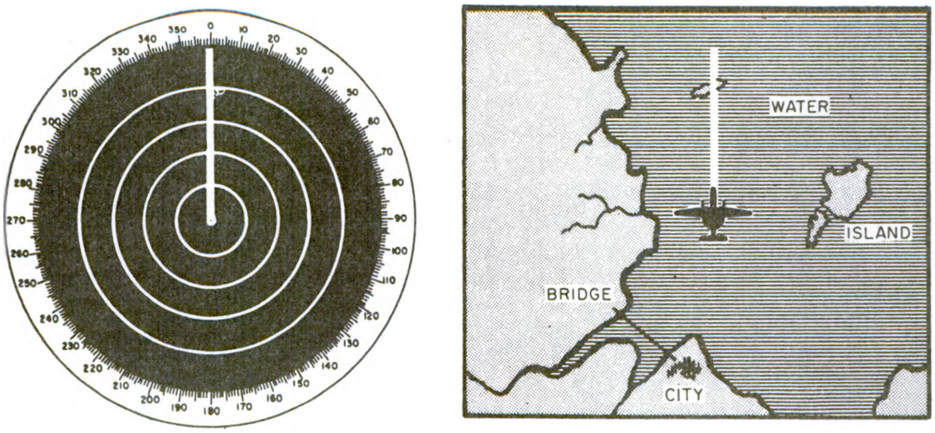
PPI-SCOPE

Type-P indicators, also called plan-position indicators (PPI), or PPI-scopes, are used primarily to present data on the range and bearing of targets. Like B- and C-scopes, PPI-scopes generally use cathode-ray tubes with long-persistence screens.

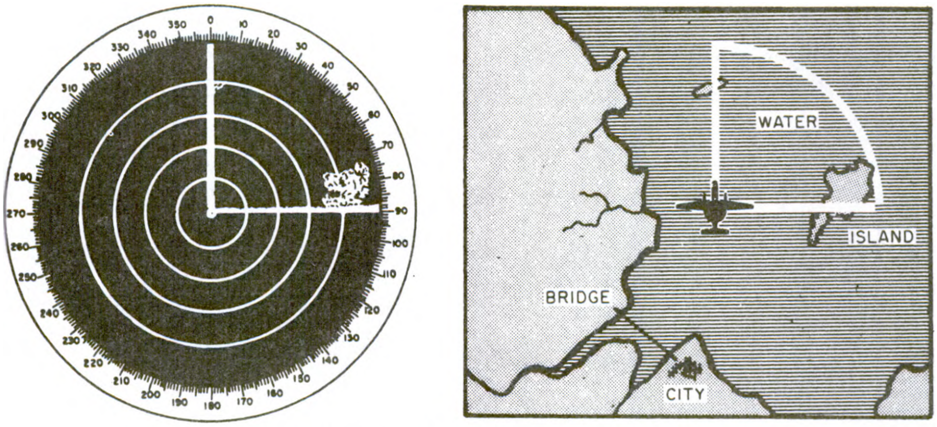
The PPI presentation is practically an exact replica of the region scanned by the radar antenna.

Distance along the radial sweep line represents target range. Rotation of the radial sweep line, in synchronism with the antenna's rotation, produces a circular display.

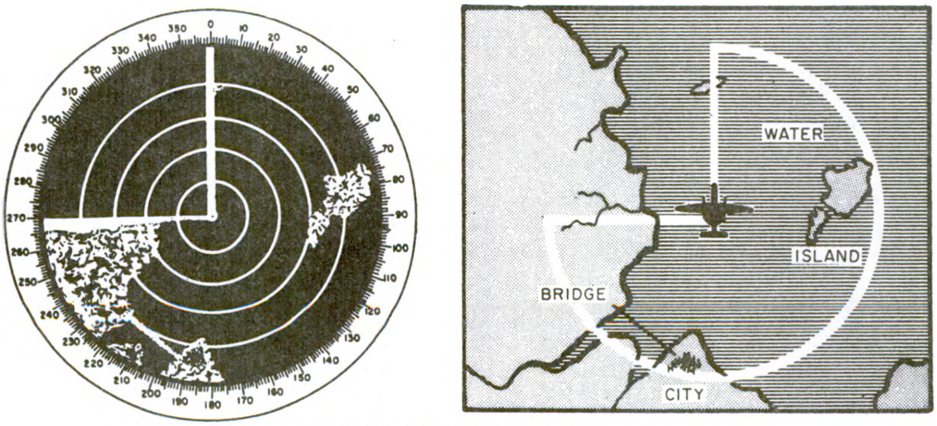
When echo signals are applied to the control grid (or cathode) of the PPI cathode-ray tube during the sweep period, the brightness of portions of the radial sweep line is increased. As in B-scopes, increasing the brightness of some portions of the PPI radial sweep line results in a maplike picture. Figure 7-30 shows a typical PPI presentation.



ANTENNA POINTING DIRECTLY AHEAD (0°)



ANTENNA POINTING TO 90°



ANTENNA POINTING TO 270°

222.114

Figure 7-30.—PPI presentation.

Normally, the center of the PPI screen represents the location of the radar. The range and bearing of the target can be determined by means of either an engraved transparent overlay, or electronic range circles and an engraved azimuth (bearing) scale. Range circles are usually obtained by adding uniformly spaced pulses to the receiver output signal during the sweep period.

The pulses cause bright spots to appear at equal intervals along the radial sweep line. When the radial sweep line rotates, the spots produce concentric circles. The distance between the center of the PPI screen and a range circle indicates a specific distance.

A movable azimuth index is frequently used to facilitate azimuth (bearing) measurements. The movable azimuth index is scribed on a glass window. The window is rotated by turning a special knob, usually mounted on the PPI chassis. When the window is rotated so that the movable azimuth index coincides with a target echo, the bearing of the target can be determined by noting the position of the index on the azimuth scale.

Figure 7-31 shows a simplified block diagram of a typical PPI-scope. In the case illustrated, the cathode-ray tube has a fixed deflection yoke. The sawtooth sweep currents required to produce the rotating radial sweep line are obtained from the trapezoidal-voltage sweep generator, a rotary transformer (synchro resolver), and two push-pull amplifiers. (See Chapter 3 of this text for a discussion on resolvers.)

The rotary transformer is a variable-ratio transformer with one primary winding (the rotor) and two secondary windings (the stator). The voltage ratio between the primary winding and each secondary winding changes when the rotor is turned.

The rotor is connected mechanically to the radar antenna. Thus, when the antenna turns, the

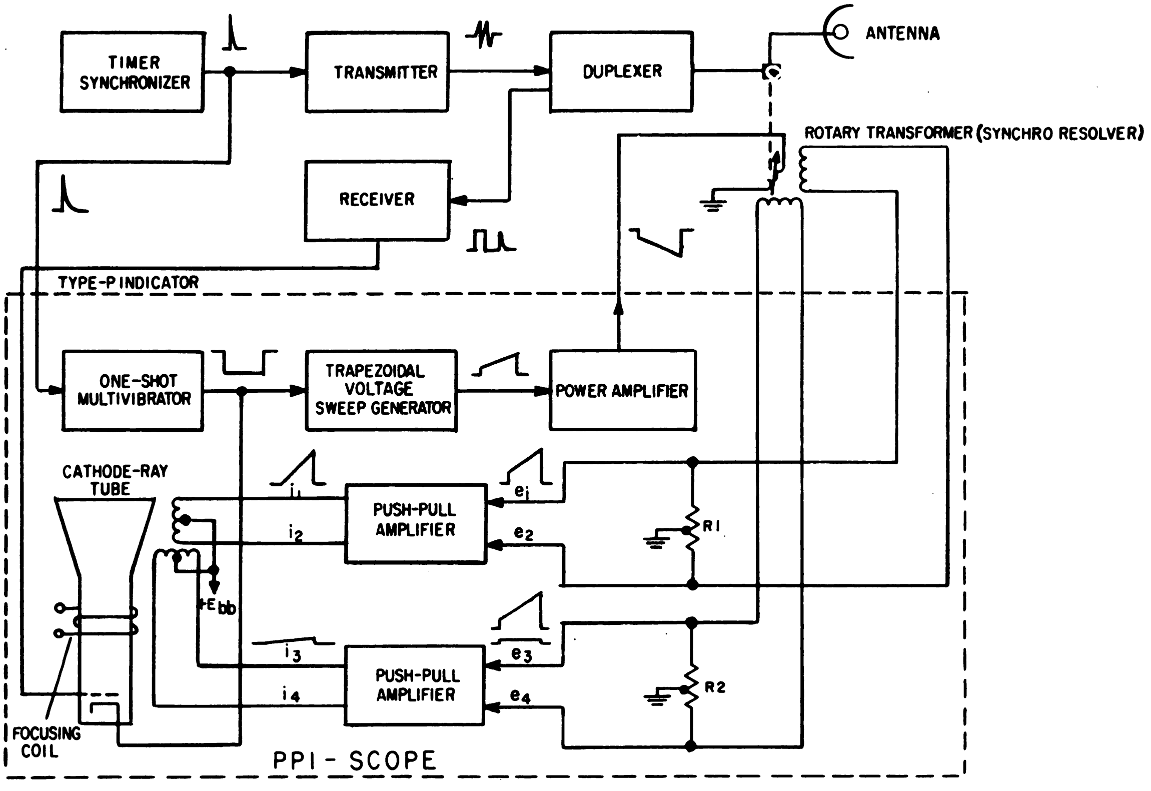


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Figure 7-31.—Typical PPI-scope, block diagram.

rotor turns, and the voltage ratio changes. One secondary voltage varies as the sine of the angle of antenna rotation; the other secondary voltage varies as the cosine of the angle of antenna rotation.

The plan-position indicator operates as follows: trigger pulses from the timer (synchronizer) are fed to both the transmitter and the one-shot monostable multivibrator. The one-shot multivibrator generates negative gate pulses that are applied to the trapezoidal-voltage sweep generator and the cathode of the cathode-ray tube.

The output of the trapezoidal-voltage sweep generator is fed to a power amplifier. The output of the power amplifier is applied to the primary of the rotary transformer. The secondary voltages of the rotary transformer are trapezoidal and have amplitudes that depend on the antenna position.

To apply trapezoidal voltages to the two push-pull amplifiers, a center-tapped resistance network is connected across each of the two secondary windings of the rotary transformer. Network R1 produces two voltages (e_1 and e_2) of equal amplitude and opposite phase, which are applied to one push-pull amplifier. Likewise, network R2 produces two voltages (e_3 and e_4) of equal amplitude and opposite phase, which are applied to the other push-pull amplifier. For simplicity, only the waveforms of e_1 and e_3 are shown in figure 7-31.

Trapezoidal voltages e_1 and e_2 produce sawtooth sweep currents i_1 and i_2, respectively. Trapezoidal voltages e_3 and e_4 produce sawtooth sweep currents i_3 and i_4, respectively. The angular position of the radial sweep line at any instant depends on the relative amplitudes and the phase relationship of the sawtooth sweep currents at that instant.

Sawtooth sweeps current i_1 and i_2 are equal in amplitude, but opposite in phase. Likewise, i_3 and i_4 are equal in amplitude, but opposite in phase. For simplicity, only the waveforms of i_1 and i_3 are shown in figure 7-31. The relative amplitudes and polarities of i_1 and i_3 (also of i_2 and i_4) vary as the rotary transformer is rotated. This causes the radial sweep line to rotate in synchronism with the radar antenna (which is geared to the rotary transformer).

In general, plan-position indicators used in conjunction with rotary transformers also use clamping circuits (clampers). The clamping circuits ensure that the scanning spot always starts from the same point on the PPI screen. The fundamentals of clamping circuits are discussed in *Basic Electronics*.

Negative gate pulses are applied to the cathode of the PPI cathode-ray tube to intensify the electron beam during each sweep period. The electron beam is intensified to the point where the radial sweep line is barely visible. When echo signals are applied to the control grid of the cathode-ray tube during each sweep period, the brightness of portions of the radial sweep line is increased.

E-SCAN (RHI)

The RHI (Range Height Indicator) presentation (figure 7-32) is another type of scan for presenting range and height information. The RHI is also known as the type-E scan. E-scan is a modification of the B-scan on which an echo appears as a bright spot with range indicated by the horizontal coordinate and the elevation (height) as the vertical coordinate. This type of scan is used in directing aircraft during ground- and carrier-controlled approaches, and in fire-control systems for terrain clearance.

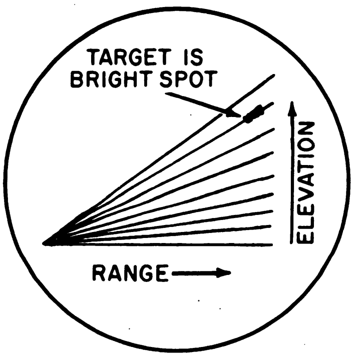

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Figure 7-32.—E-scan presentation.

DEFLECTIONS AND SWEEPS

The various types of deflection and sweep circuitry required for a typical radar indicator system are shown in figure 7-33 (A). These circuits, together with the receiver circuits, are contained in a unit called the receiver-indicator. Figure 7-33 (B) shows the waveforms for this indicator system when set for a 30-mile range sweep.

Negative trigger pulses from the timer are applied to the sweep multivibrator. When a negative trigger pulse is applied to it, the sweep multivibrator causes a switching action which initiates the sweep voltage in the PPI sweep generator.

When the sweep voltage reaches a predetermined level, the sweep-limiter circuit conducts, and causes a second switching action.

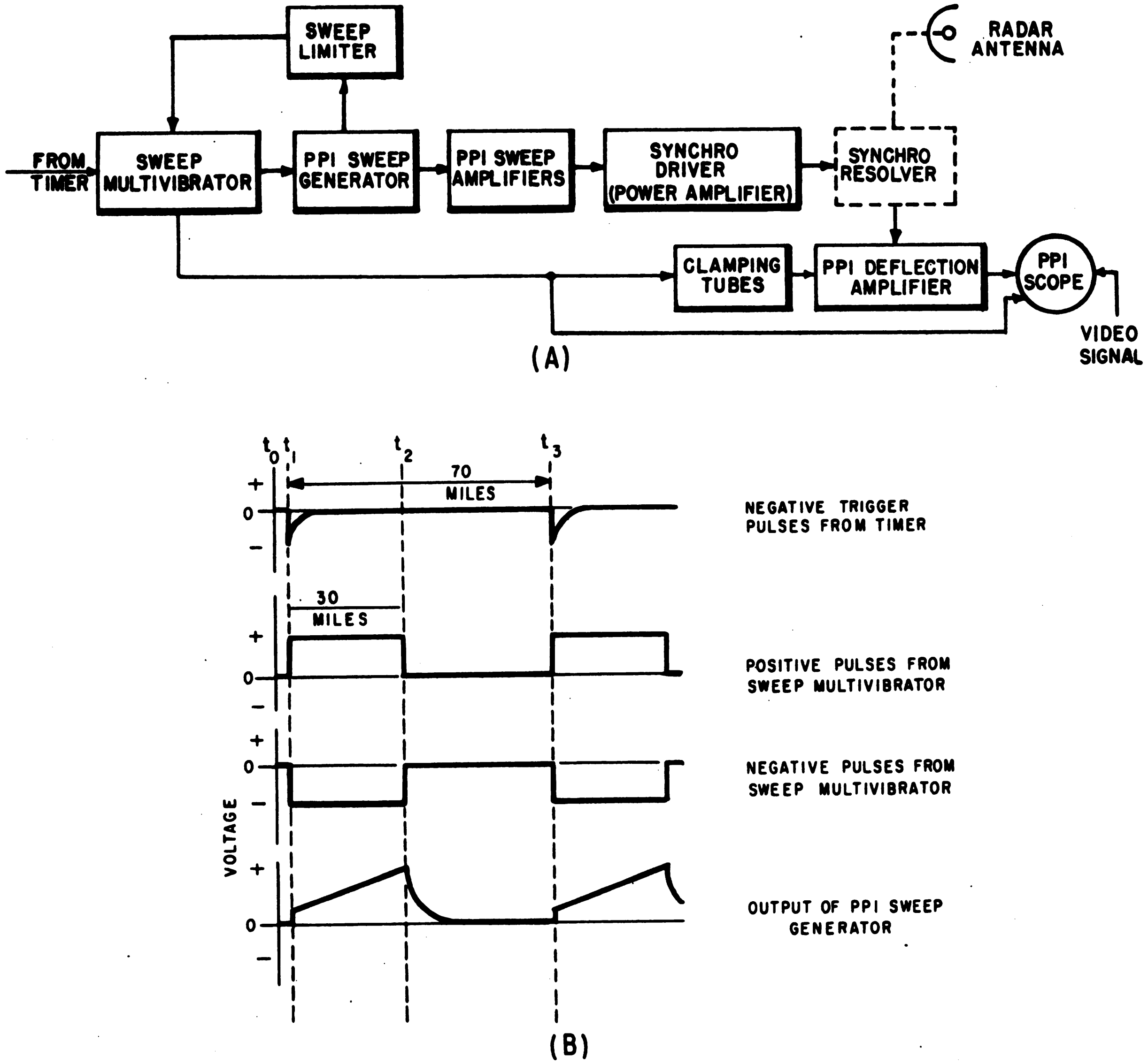

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Figure 7-33.—(A) Typical indicator, block diagram; (B) waveforms 30-mile sweep.

As a result, the sweep multivibrator produces positive and negative rectangular pulses, as shown in figure 7-33(B). The positive rectangular pulses are applied to the PPI sweep generator which produces a trapezoidal voltage.

The trapezoidal voltage is amplified by the PPI sweep amplifiers, and then applied to the synchro driver (power amplifier). The output of the synchro driver is applied to the rotor of a synchro resolver.

The synchro resolver has two stator windings and one rotor winding. The rotor shaft is mechanically coupled to the radar antenna. When the antenna rotates, the synchro-resolver rotor turns, the trapezoidal-sweep voltages of varying amplitude are induced in the synchro-resolver stator windings. The amplitude of the induced sweep voltages, at any instant, depends on the angular position of the rotor winding with respect to the stator windings of the synchro resolver.

The induced sweep voltages are amplified by the PPI deflection amplifiers, and then applied to the deflection coils of the PPI-scope. As a result, a radial sweep line is produced on the PPI screen. Because of the mechanical coupling between the radar antenna and the synchro-resolver shaft, the radial sweep rotates in synchronism with the antenna.

The negative rectangular pulses from the sweep multivibrator are applied to the clamping tubes and the cathode-ray tube of the PPI-scope. The clamping tubes ensure that the PPI electron beam always starts its sweep trace from the same point on the PPI screen.

The negative rectangular pulses applied to the cathode-ray tube intensify the scope electron beams during the sweep time. This produces a faintly visible trace on the scope.

Radial Sweep Line

The radial sweep line on the screen of a plan-position indicator is obtained by sweeping the electron beam from the center to the edge of the PPI screen. To obtain azimuth (bearing) indication, the radial sweep line is rotated about the center of the screen, like a spoke of a wheel. Two different methods that are used to produce a rotating radial sweep line are mechanical azimuth sweep and electrical azimuth sweep.

In mechanical azimuth sweep (figure 7-34(A)), a rotating deflection yoke is used. The yoke is mounted in bearings, and is rotated mechanically around the neck of the cathode-ray tube, in synchronism with the radar antenna.

When a sawtooth sweep current is applied to the deflection coil through the sliprings, as shown in figure 7-34(B), a sawtooth magnetic field is produced. The magnetic field causes the electron beam to be deflected, thereby producing a radial sweep line. The amount of beam deflection, and consequently, the length of the radial sweep line, depend on the amplitude of the sawtooth sweep current.

The direction of beam deflection, and consequently, the position of the radial sweep line, are always perpendicular to the magnetic field. Thus, when the deflection yoke rotates, the deflection coil rotates, and the magnetic field also rotates.

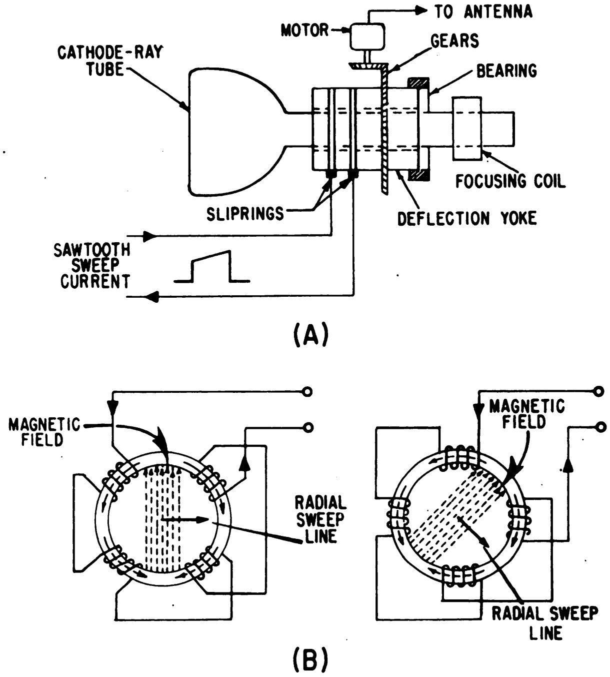

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Figure 7-34.—Mechanical azimuth sweep. (A) Rotating deflection yoke; (B) relationship between sweep direction and yoke position.

Since the electron beam is always deflected in a direction perpendicular to the magnetic field, the radial sweep line also rotates. A radial sweep line is produced each time a sawtooth sweep current is applied to the deflection coil. The radar antenna and the rotating yoke are always rotated in synchronism.

The second method of producing a rotating radial sweep line is called electrical azimuth sweep. This system uses a fixed deflection yoke with horizontal- and vertical-deflection coils. Sawtooth sweep currents are applied simultaneously to the two deflection coils. The direction of the radial sweep line obtained depends on the relative amplitudes of the two sweep currents. Unlike mechanical azimuth sweep, electrical azimuth sweep has practically no mechanical difficulties.

In the foregoing paragraphs, frequent mention has been made of the PPI sweep generator circuits. Some of the fundamentals of sweep generators are covered in *Basic Electronics* in connection with special circuits and cathode-ray tube fundamentals.

MISCELLANEOUS PRESENTATIONS

Many other types of radar indicators are used in addition to A-scopes, B-scopes, C-scopes, and PPI-scopes. It is not unusual to find more than one type of presentation incorporated into one indicator.

Most indicators used in aviation fire control radar use two or more electron guns. One gun is used to develop a B-type presentation while the other gun or guns develop the various elements of a so-called attack presentation.

These elements may consist of an elevation strobe, artificial horizon, steering information, acquisition circle, and range circle. Coverage of all these elements with the time sharing necessary for proper display is discussed in Chapter 8 of this manual. However, the range circle element is discussed in succeeding pages of this chapter.

RANGE CIRCLE GENERATOR

The indicator of a typical aircraft weapons systems radar uses a circle for range presentation. The size of this circle will be directly proportional to the target range. Figure 7-35 is a simplified schematic diagram of a range circle generator. You should already be familiar with the method of producing a circle on a CRT by applying two sine waves, 90° out of phase, to the deflection plates of the CRT. The size of the circle is controlled by the amplitude of the sine wave inputs.

The range circle generator (figure 7-35) provides two sine wave signal outputs 90° out of phase with each other. The amplitudes of each signal are controlled by a dc range signal from the tracking unit. Inputs to the circle generator are a 500-Hz reference signal and the dc range voltage from the tracking unit. The 500-Hz signal is applied to amplifier transistor Q7 through capacitors C1 and C2 and resistor R7. Resistor R7 is part of a voltage divider consisting of R7 and a resistor contained in raysistor K1504 (a raysistor is a series of switching devices, the output consisting of a photoresistor which may be excited by various forms of electrical lights). Resistance of the raysistor resistor varies with the intensity of the raysistor light L1.

Output for transistor Q7 is applied to signal emitter follower Q8 and to feedback emitter follower Q6. The output of Q6 is rectified by the action of diodes CR1 and CR2 to obtain a positive voltage whose amplitude is proportional to the ac signal. This positive voltage is applied through emitter follower Q2 and resistor R5 to transistor Q1. Also applied to transistor Q1, through resistor R1, is the dc range voltage. The resulting effect is a voltage on the base of Q1 that is proportional to the dc range voltage and the dc feedback voltage. The output of Q1 varies the intensity of L1, which in turn varies the resistance of the raysistor resistor. Therefore, the resistance of K1504 is proportional to the output of Q1. This directly controls the amplitude of the output of Q7, since it is part of its input voltage divider. Thus the output amplitude of Q7 is controlled by the dc tracking range input voltage to Q1. The output of Q7 is applied to emitter follower Q8, then on to buffer amplifier Q3 through potentiometer R34, which ultimately adjusts the diameter of the displayed circle.

Two outputs are taken from transistor Q3. One is applied through a lagging phase shift network consisting of potentiometer R16 and

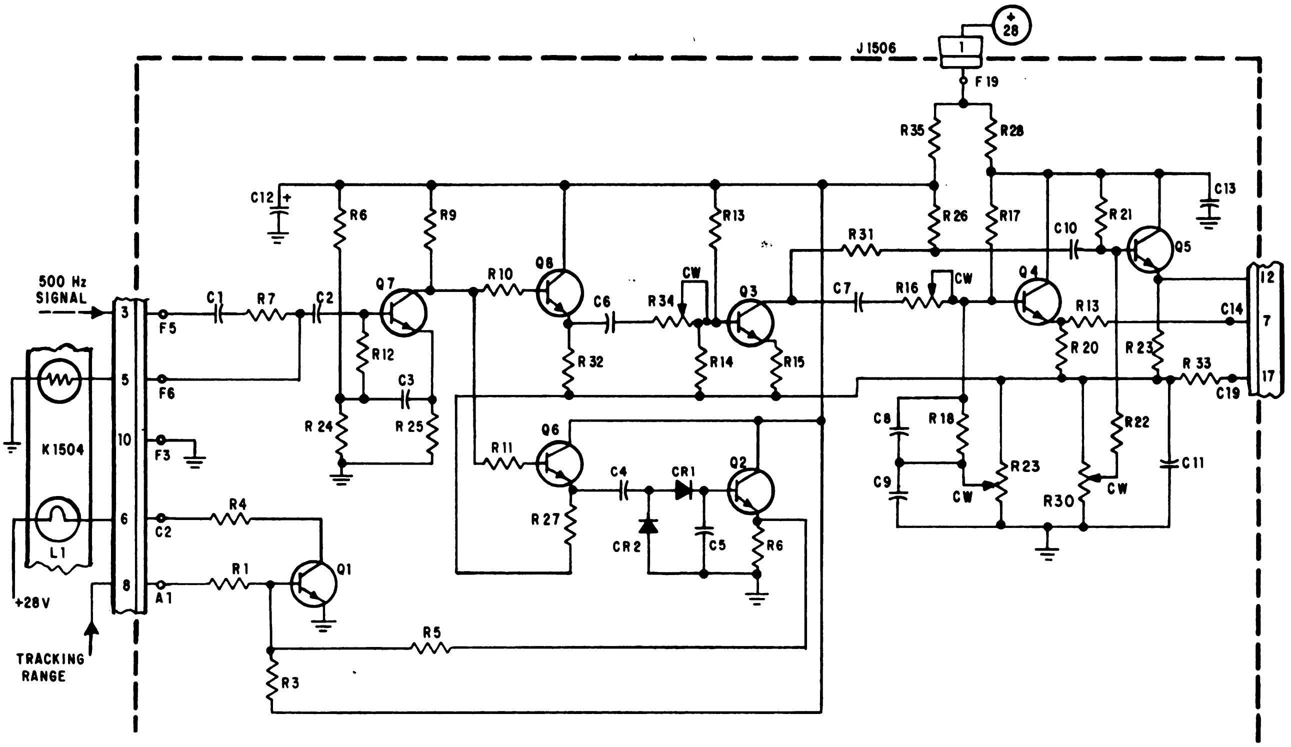

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Figure 7-35.—Range circle generator.

capacitor C8 to emitter follower transistor Q4; the other is applied through leading phase shift capacitor C10 to emitter follower transistor Q5. Thus, the outputs of Q4 and Q5 are 500-Hz sine wave voltages phase-shifted by 90° with their amplitudes controlled by the dc range voltage. Potentiometer R16 provides a fine adjustment of the phase shift. These two outputs, 90° out of phase, are applied to the deflection amplifiers to produce a circular trace on the cathode-ray tube.

MICROELECTRONICS

The trend toward miniaturization began with the development and subsequent use of the transistor and the solid state diode. These devices tremendously decreased equipment weight and bulk. For example, the weight of airborne navigation and communications equipment decreased as much as 50 percent during the first decade of transistor use, and the reduction in bulk was even more spectacular—transistors permitted the computer to go airborne.

However, it was not until the development of solid state devices reached the point where truly integrated circuits were a reality that a new plateau was reached and a breakthrough from miniaturization to microminiaturization was achieved. In the near future, microminiaturization (or microelectronics as it is now termed) promises an almost unbelievable reduction in size and weight, with an increase in reliability and lower lifetime costs.

Lifetime cost (the cost of the initial equipment plus the cost of maintaining it in operating condition) is an important factor economically and operationally. High reliability and good maintainability are prerequisites to low life-time costs; both are inherent in the microelectronics program.

MICROELECTRONIC TERMINOLOGY

Each time a new development appears in any field there are usually new descriptive terms and phrases to describe or explain the new methods and devices.

In the new field of microelectronics there has also evolved a new terminology. Although the definitions of the new terms have not yet become precise, and some no doubt will be changed, a few of the more common presently in use are listed below:

1. Active device—A component displaying gain or control such as transistors, diodes, or vacuum tubes.
2. Passive device—A component displaying no gain or control such as resistors, capacitors, inductors, etc.
3. Discrete component—Individual non-integrated active or passive components. Includes all components listed in 1 and 2 above.
4. Thin film circuit—A network of passive devices and interconnections formed in thin layers on a nonconducting substrate (base) by spray, vapor, or sputtering process.
5. Substrate—The physical material upon or within which a circuit is fabricated.
6. Integrated circuit—A number of active and/or passive devices formed on or within a continuous body or substrate (usually silicon semiconductor) and interconnected with deposited metal patterns to perform a given function.
7. Hybrid circuit—A packaged circuit consisting of a combination of one or more integrated circuits and/or discrete components or thin film devices, used to achieve a given function.

PURPOSE

The primary purpose of this new trend in electronics is to develop building blocks, with each block performing the function of a circuit or a system, which will accomplish the following objectives:

1. Performs more electronic functions per unit of volume, weight, cost, power input, and power dissipated than is possible with the most advanced presently available components and circuit assembly techniques.
2. Possess considerably higher reliability than their conventional counterparts which will reduce maintenance to a minimum.
3. Be low priced, making "throwaway maintenance" economically feasible.
4. Performs new functions not possible with present components.

Size reduction alone is not always the aim of microelectronics. Although small size and reduction in weight are very important in many cases, there are applications where these characteristics are not important enough to justify the time and expense to develop an entirely new form of systems fabrication. The reduction in size in this technology is an inherent feature.

TECHNIQUES

Basic techniques and materials to design and fabricate a limited number of microelectronic circuits are now available. However, additional extensive research and development are required to provide suitable materials and techniques to satisfy the demand for other circuits and for improved performance and reliability at a reasonable cost.

The thin film microelectronic process is based on fabricating complete functions or circuits by depositing thin films on substrates. The various elements of the circuits, therefore, cannot be disconnected from each other. The method most generally used in fabricating the thin film circuit is to evaporate a metal or dielectric in a high vacuum and condense the vapor on a thin, inactive support wafer or base (substrate). Carefully prepared masks are used to control the areas on which these metals or dielectrics are deposited. Presently, resistors, capacitors, and conductors can be deposited quite conveniently. Note that the components are still referred to, the same as they were in the past. The differences are that there are no component leads and that the interconnections are an integral part of the circuit.

The basic advantages of this technique are the high density of the components, the sharp decrease in the number of connections, and the replacement of soldered and mechanical connections by the more intimate ones formed at the time the material is deposited. Some of the problems that remain are heat dissipation, interconnections between circuit wafers, and stability of the components during and following the "packaging" of the circuits. Still lacking is a technique for depositing active elements. Such a technique would be a major improvement over present methods in which the active element is produced separately as a discrete component and inserted into the thin film circuits.

Figure 7-36 shows the basic steps in fabricating a simple thin film, flip-flop circuit. The original

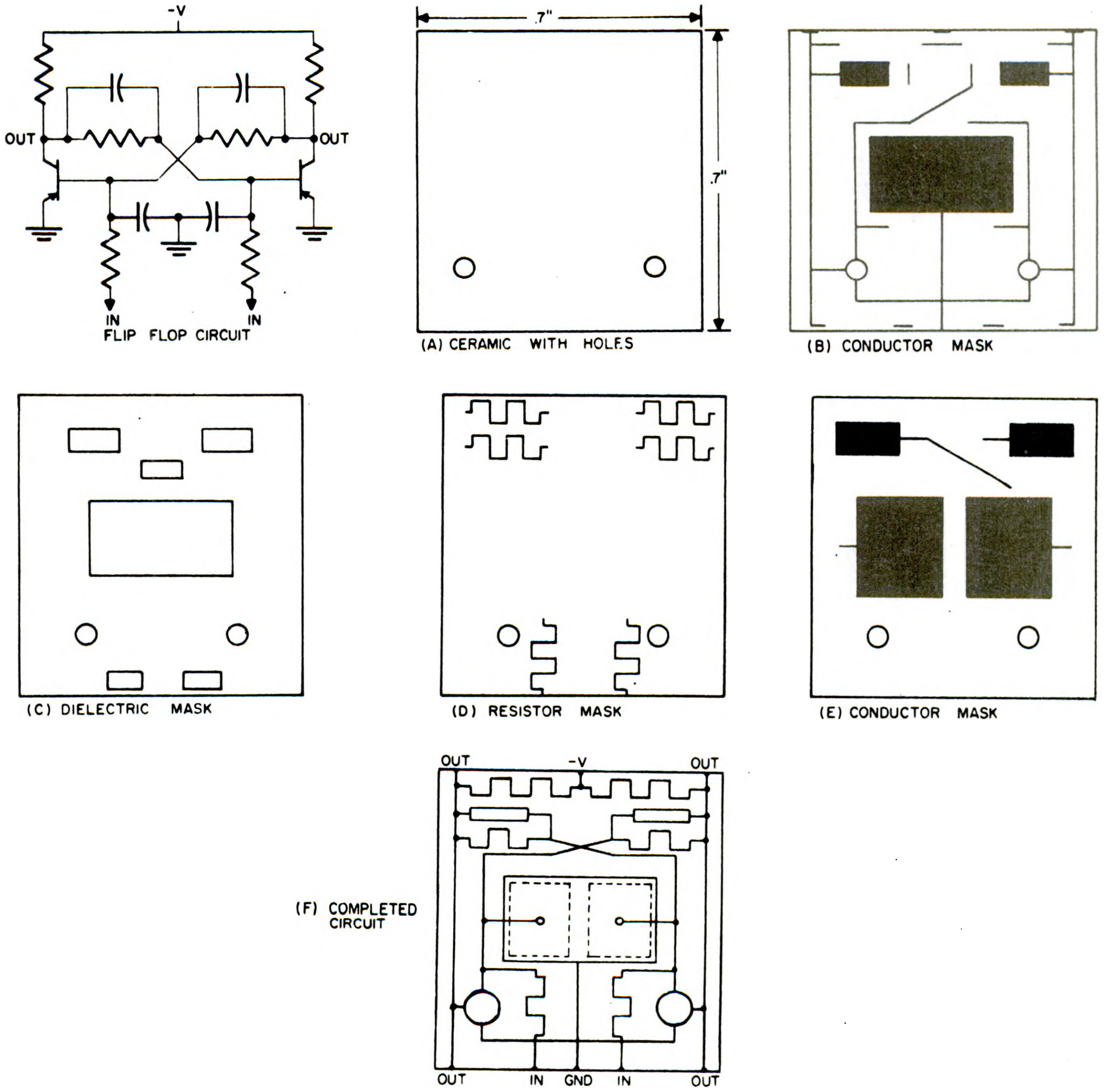

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Figure 7-36.—Fabrication of a thin film, flip-flop circuit.

substrate (A) has two drilled holes to accommodate the transistors. The mask used when the conductors and one of the two electrodes for each of the four capacitors are deposited is shown in figure 7-36(B). The capacitor dielectrics and crossover insulation points are then deposited (C). The resistor mask is shown in figure 7-36(D), and the mask for the second electrode of each of the four capacitors is shown in (E). The complete wafer is shown in (F).

APPLICATIONS

The following are but a few examples of the many microelectronic applications presently in use or being developed for naval aviation.

An air-sea rescue transceiver unit has been produced which provides two-way voice communication and transmits a beacon signal for a continuous period of 24 hours. This entire unit weighs three-fourths of a pound and requires 8.4 cubic inches of space (a little larger than a package of cigarettes).

The Loran C Navigation Set was reduced in weight by approximately 100 pounds with the use of about 900 microcircuits. Reliability of this particular equipment was increased nearly five-fold and space requirement was reduced by 1.25 cubic feet. Other equipments include computers, missiles, fuzes, and other ordnance devices.

SUMMARY

This chapter described the circuits of a typical pulsed type radar. The major components that were emphasized are the synchronizer, transmitter, receiver, and indicator. The following is a summary of the chapter contents:

RADAR—A radar system consists of a transmitter which sends (transmits) RF signals, a receiver which is located at the same site, and an indicator which gives a visual indication of echoes returned by a target. In addition, most radar systems have a provision for ranging (measuring the range) on a received echo. Some radars can automatically track the echo.

SYNCHRONIZER—The basic function of a radar timer is to synchronize the sweep voltage or current for the indicator with the transmitter pulse. The specific function is to produce the trigger pulse that starts the transmitter, the sweep circuits, the rangemark generators, blanking circuits, and gating circuits.

Radar systems may be classified as either a self-synchronized system, or an externally synchronized system. The transmitter provides the timing trigger pulses in a self-synchronized system. A master oscillator, normally external to the transmitter, provides the timing trigger pulses in an externally synchronized system.

RANGING—The accuracy of target-range data provided by a radar varies. In some applications of radar, the indicator sweep is calibrated by a transparent overlay with an engraved scale. In other applications, electronic range marks are supplied to the indicator.

In a radar system that requires extremely accurate target-range data, a movable range marker may be used. The range marker is normally a movable range gate or step. In some cases, movement of the range marker is accomplished by turning a calibrated control. In other cases, the range marker may be used as a range gate for automatic range tracking.

TRANSMITTER—A transmitter develops high-power, high-frequency pulses of RF energy. They are radiated into space by the antenna system. Basically, the transmitter is an RF oscillator which is turned on and off by a modulator.

The modulator controls the pulse width of a radar transmitted pulse. The peak power of the transmitted pulse is also influenced by the modulator.

There are two types of modulators—the line-pulsing modulator and the drive-hard tube modulator. The one that is used most extensively is the line-pulsing modulator. It makes use of pulse-forming network to store energy and form pulses.

RECEIVER—Radar systems generally use high-gain, low-noise, superheterodyne receivers. A receiver consists basically of the following components:

1. Local oscillator—Provides a controlled frequency to the radar crystal detector for development of the IF.

2. Crystal mixer—Combines RF and local oscillator signals to produce sum and difference frequencies. Most receivers use the difference frequency as the IF.

3. IF amplifier—Amplifies the input signal to the level required to operate the detector of the radar. (Must also provide proper bandwidth for passing important sidebands of the IF signal.)

4. Radar detector—Recovers the envelope of the RF carrier or detects the IF signal. The detection provides a video signal to the video amplifier for amplification.

5. Video amplifier—Amplifies the video signal to a high enough level for use by the radar presentation system.

6. Radar indicators—Presents radar data for visual analysis. Consider the following:

a. A-scope.—Presents range as a horizontal time line. Vertical indications are transmitted pulse and target video.
b. B-scope.—Presents a possibility of three variables—range, a function of time; azimuth, a function of antenna rotation; and the intelligence received (target data.)
c. C-scopes.—Presents data on the bearing and elevation of targets. The horizontal axis represents bearing; the vertical axis represents elevation.
d. PPI-scopes.—Presents range and bearing of targets. In effect, presentation is a replica of the region scanned by the radar antenna.
e. E-SCAN (RHI).—Presents range and elevation or height information. Range is the horizontal coordinate on the indicator; elevation (height) is the vertical coordinate.

MICROELECTRONICS—Provides for an extreme reduction in the size and weight of electronic equipment. Also, an increase in the reliability and lower lifetime costs of equipment is realized.

CHAPTER 8

WEAPONS CONTROL RADAR SYSTEM

The purpose of this chapter is to acquaint you with a complete radar system which is operationally representative of those found in modern weapon system installations.

The radar system that we have chosen for presentation is the Radar Maintenance Trainer Device 11D13A. This system was selected because an actual operational system would require that classified information be included. Since the trainer is different from an operational system in some respects, these differences are noted when discussion will not violate security regulations.

The device 11D13A includes all the elements essential for basic search radar ranging—transmitter, receiver, antenna, and synchronizer circuits. Additional elements including tracking, stabilization, and target generation (simulated targets) allow operation as either a fire control (intercept) radar or a bomb director radar. The target generator unit, although not usually contained in operational radar systems, produces and controls the target in a manner typical of analog computing systems. It contains both mechanical and electronic elements found in analog computing systems. A block diagram of the trainer is illustrated in figure 8-1.

MODES OF OPERATION

The trainer 11D13A is capable of operating in three basic modes which are then divided into submodes. These submodes parallel the general modes in actual weapons control systems. The three modes available in the trainer are search, fire control, and bomb director.

The trainer has no standby mode as such. (The purpose of a standby mode is to apply filament voltages for initial warmup before selecting an operating mode.) Most radar sets include an automatic time in (time delay) circuit which prevents application of power to the high voltage sections prior to the necessary warmup period.

The term acquisition, as used in operation of a radar set, refers to a momentary mode of operation. The time period for acquisition begins at the moment the operator depresses a control switch transferring antenna control from automatic search to manual search. During this period the operator has complete control of antenna position, both in azimuth and elevation, and may also control a symbol on the indicator called an acquisition symbol. By placing the acquisition symbol over the selected target, the operator causes coincidence between the tracking gate and the target in the range and tracking circuits of the radar. Acquisition is complete when lockon occurs and the system switches to automatic track.

SEARCH MODE

Search operation for airborne and ground targets is provided with ranges of 0 to 6,000 yards and 0 to 12,000 yards. In this mode the antenna automatically scans the horizon, rotating in either direction up to 6 rpm. Manual control of the antenna in this mode provides manual tracking of detected targets. There is some minor difference in the method of manual control. The difference, however, is of little consequence and will be noted at the appropriate time. Range marks are selectable in 1,000-, 2,000-, or 3,000-yard increments, although actual weapons control radars have much longer ranges. In the basic

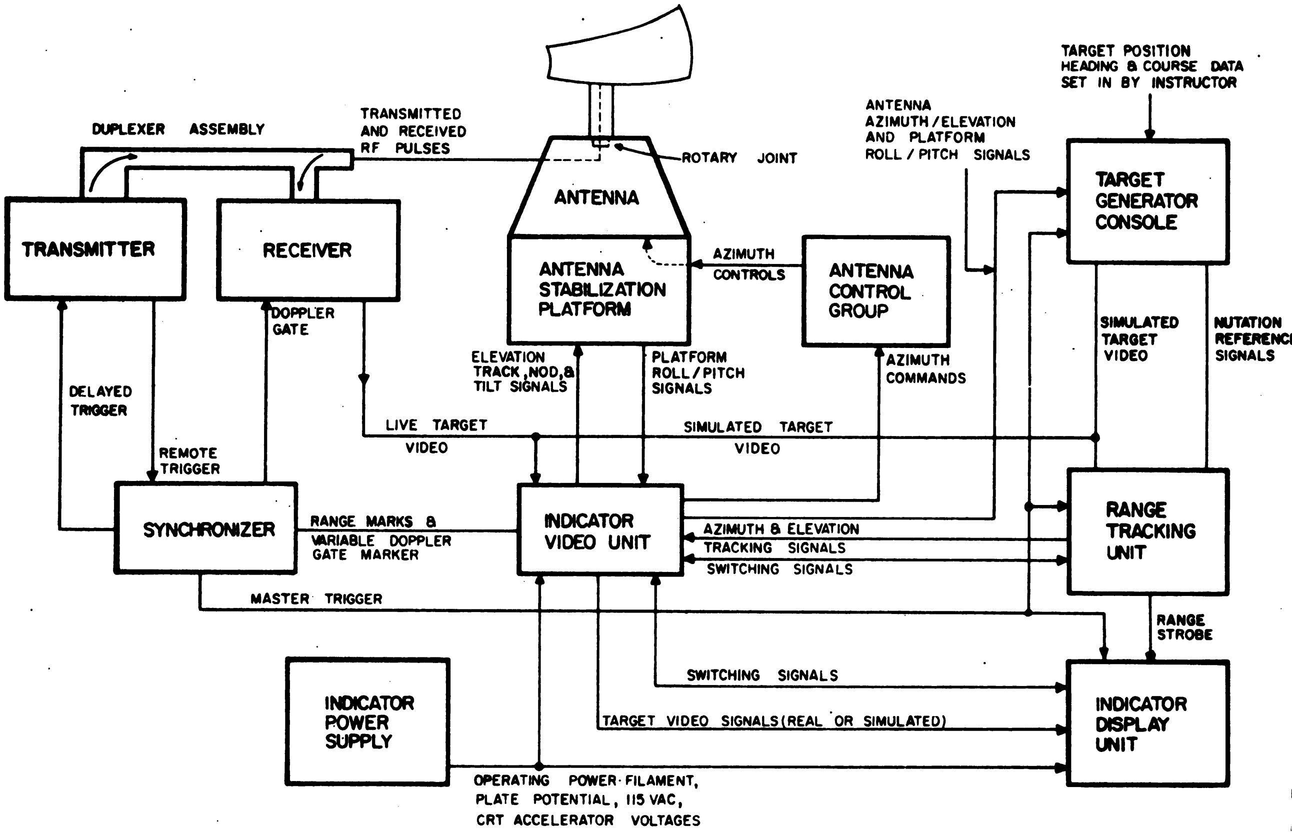

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Figure 8-1.—Trainer 11D13A functional block diagram.

search mode, the B-scope, which is also included in the indicator unit, is deactivated.

FIRE CONTROL MODE

When the fire control mode is selected, the target simulator provides a three dimension target (target with range, azimuth, and elevation information). In the fire control mode there are five submodes: automatic search, manual search, acquisition, automatic track, and breakaway. These five submodes permit the simulated target to be detected initially, manually tracked and acquired, and tracked automatically until minimum range is reached. At this time, a breakaway signal in the form of an X is displayed on the B-scope indicator, warning the operator to break away from the target. In an actual weapons radar, the X also means that the aircraft is too close to the target to allow time for an air-to-air missile to properly track the target.

Minimum range in fire control operation is 3,500 yards. Three ranges are provided for target information while operating in the fire control mode—0 to 10,000, 0 to 40,000, and 0 to 80,000 yards. During this mode of operation, target information is displayed on both the PPI and B-scope of the indicator display unit. The B-scan display uses a dual-gun arrangement (to be discussed later) which provides steering information in addition to the normal plot display.

BOMB DIRECTOR MODE

Operation in the bomb director mode covers the same ranges provided in the fire control mode. Aiming data are displayed on both the PPI and

B-scope displays. Switching circuits, which are energized at the time of mode selection, cause the presentations to be altered to conform to typical bomb director system presentations. The PPI display has a depressed-center sector scan at twice the scale of the fire control mode, and the B-scan reflects the target area at five times the scale of the PPI. Both indicators include controllable range and azimuth marks (strobes) which act as crosshairs to facilitate aiming (aim point tracking).

SYSTEM CONTROLS

Through the manipulation of the basic controls, the operator has available all of the previously mentioned modes of operation. The controls of the trainer are decentralized to simplify construction and operation, but these controls can be grouped into five major categories according to their function. The five major control functions are:

1. Power switch.
2. Mode switch.
3. Receiver gain control.
4. Antenna azimuth and elevation control.
5. Range control.

POWER SWITCH

The power switch is the system's off-standby-operate switch and may have several operate positions. The off position, of course, removes all power from the system. The standby position, as previously described, applies filament power and keep-alive voltage to the TR tubes. For purposes of training, the 11D13A has a power switch for each of the major units (antenna, transmitter, and so forth). This allows for operation of each of the units or any selected combination of units for training. During the discussion throughout this chapter, the appropriate control will be noted along with its function and the relation to one of the four major function controls, if necessary.

MODE SWITCH

The mode switch is practically self-explanatory. In the trainer, this switch sets up one of the basic operating modes available, such as search, bomb director, or fire control.

RECEIVER GAIN

The receiver gain control is one of the most important controls available to the operator, whether the pilot in an aircraft or an operator on a trainer. This control, if not properly adjusted, will prevent the entire system from operating at peak performance. Some radar systems include a built-in test function which provides a reasonable check of the adjustment of the receiver gain control. This control is normally adjusted for best definition of the weakest target available. To obtain peak detection (which provides maximum range), there is only one acceptable method for adjusting this control. In each particular radar, this method is part of the minimum performance test.

ANTENNA CONTROL (HAND CONTROL)

The hand control of an actual radar installation allows the operator to select manual search operation and also allows selection of targets. Through the use of this control the operator may command the radar to acquire and/or release the target.

During automatic search, this control has but one function. This is to position the antenna in elevation to select the area to be searched in relation to the horizon. It can be seen that this control and the receiver gain control are very important because they will affect target detection performance.

During manual search the hand control has complete control of the antenna and, in addition, also controls the acquisition symbol to acquire the target.

AUXILIARY CONTROLS

Through the use of a scan switch in an operational radar, the operator may select either full azimuth or sector scan. The trainer likewise incorporates a scan switch, which may be used to select the type of scan desired. In the trainer the selections are automatic sweep at a 6 rpm rate, variable sweep from zero to 6 rpm manually controlled, or sector scan.

INDICATOR DISPLAYS

A description of the indicator displays (PPI or B-scope) in the three basic modes of operation and the submodes of fire control is given in the following paragraphs. The indicators are used to monitor system performance during simulated operation in all weather conditions.

BASIC SEARCH

In the basic search mode, information is displayed on the PPI only. As shown in figure 8-2, the PPI scan presentation may be a map-like picture of the Earth's surface being scanned. The range sweep line rotates in synchronization with the antenna through a full 360° cycle. Targets appear on the face of the CRT as an intensified light spot. The range of the target is indicated by its position on the radius of the range sweep line, and target azimuth position is indicated by the angle of the sweep line at the time the target is painted. The top of the scope is 0° and may indicate dead ahead.

If 1,000-yard range marks are selected, then the two range marks shown in the figure are 1,000 yards apart. Starting from the center of the scope and moving outward toward the edge of the scope face, the first range mark then indicates targets from zero to 1,000 yards. In the figure there are two targets shown that are between the 1,000- and 2,000-yard marks. Other targets are illustrated at greater ranges and at different azimuth positions. The presentation illustrated could be a ground map of an area of the Earth's surface showing several islands. The shape of the target appearing on the scope will be almost the actual shape of the target as viewed visually. If, however, the antenna were scanning above the horizon, an airborne target would be a very small bright spot and target shape would not be defined.

FIRE CONTROL (AUTOMATIC SEARCH)

In the automatic search submode of fire control, information is displayed on both indicators. The PPI presents target range and azimuth information as before. Now, the B-scope also presents information that, if the system were operating in an aircraft, would be required to make a successful attack on an airborne target. This information is illustrated in figure 8-3.

In figure 8-3, which is a normal B-scan search display, four items of interest are painted

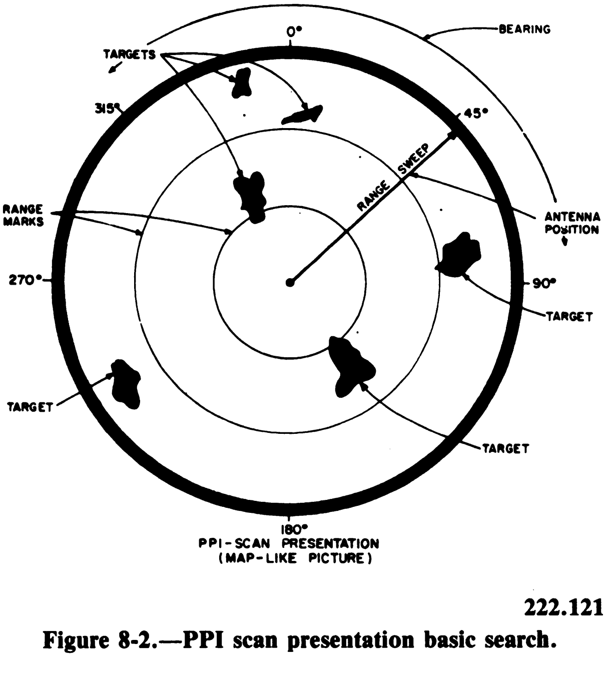

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Figure 8-2.—PPI scan presentation basic search.

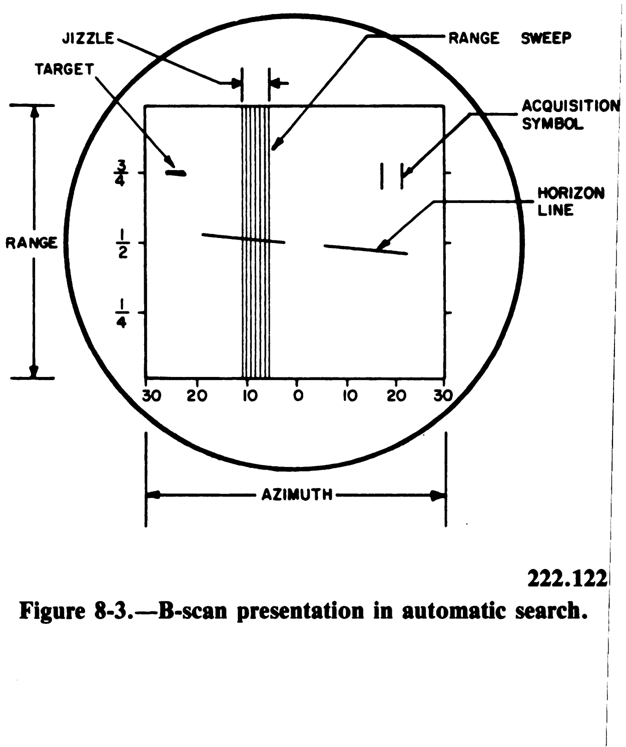

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Figure 8-3.—B-scan presentation in automatic search.

electrically on the face of the CRT. The first is the range sweep line, sometimes referred to as the B-trace. This time, however, the sweep is from the bottom of the scope to the top. Range on a B-scope is measured from the bottom of the scope to the top. The length of the trace then is equal to the range selected. If the 0- to 10,000-yard range is selected, the length of the range sweep line is 10,000 yards. The position of the sweep line on the face of the scope, as was the sweep line on the PPI, indicates the azimuth position of the antenna. The trace scans back and forth following the antenna.

It should be noted that the scan line is not a single line, but is made up of several lines, causing it to become quite wide. This is called "jizzle" and is the result of simulated antenna spin modulation, as described in Chapter 3. In an actual radar system, this is accomplished by nutation of the antenna feed horn or reflector dish. In the trainer a scan generator produces the effect of the antenna nutation, but the antenna is not actually nutated. Figure 8-4(A) illustrates an antenna pattern which is simulated in the trainer. Note also in part (B) of the figure that there is a box-like pattern produced. This is accomplished by introducing a nod at the end of the scan.

The second item on the scope is video (targets). As the antenna scans back and forth, any target within range of the radar appears as a bright spot on the face of the CRT. The range of the target will be indicated by its vertical distance from the bottom of the scope. The azimuth position of the target is indicated by the position of the target either to the left or to the right of the center. For example, if the target appears as shown in figure 8-3, its range is 7,500 yards (on the 10,000-yard range scale) and is to the left of the attacking aircraft. Most radars installed in fighter-type aircraft also have an indication of the antenna tilt which is used to indicate elevation position of the target relative to the attack aircraft. If the target were above the attacking aircraft, the antenna would have to be tilted up in order to receive a target echo. The amount of tilt can then be read from the indicator, and the pilot may steer the aircraft accordingly to intercept the target.

The third item on the B-scope is the acquisition symbol. During automatic search, the acquisition symbol is relatively unimportant but is movable and could be used to mark the area of target return. The symbol, as shown in figure 8-3, is made of two short vertical lines slightly separated. Position of the symbol in the vertical indicates range, and is controlled by the range circuits, which in turn are controlled by the hand control in an actual radar system. Movement of the hand control back or forward decreases or increases range voltage which causes the acquisition marks to move in or out in range. The acquisition marks are also controllable in azimuth, by movement of the hand control either to the left or to the right. Therefore, the acquisition marks may be positioned anywhere on the face of the scope. This is described in greater detail later.

The fourth symbol on the face of the scope is the artificial horizon line. This symbol is a straight line with the center blanked out and is positioned horizontally on the face of the indicator tube. The purpose of the horizon line is to indicate aircraft attitude. In automatic search the horizon line represents the Earth's horizon and when the aircraft rolls or pitches, the artificial horizon banks or moves up or down in accordance to aircraft movement. This movement of the horizon line is controlled by outputs from the aircraft vertical gyro or stable platform.

FIRE CONTROL (MANUAL SEARCH)

Manual search allows the operator to stop the antenna from scanning and directs it toward any desired target which had been detected during automatic search. Tilt or elevation control of the antenna which was provided in automatic search is still available in manual search. In addition, control of the antenna in azimuth is now available. In the operation of an actual radar installation, control of the antenna in both elevation and azimuth is a function of the hand control. In the trainer, however, azimuth and elevation controls are separate. The provision of separate controls is of no great significance, except for convenience of operation.

When manual search is initiated, the acquisition marks move to bracket the range sweep line (B-trace) and both the B-trace and the acquisition marks move together in azimuth. The position of the acquisition marks in range is also available in the manual search mode. This allows them to be positioned anywhere on the B-trace

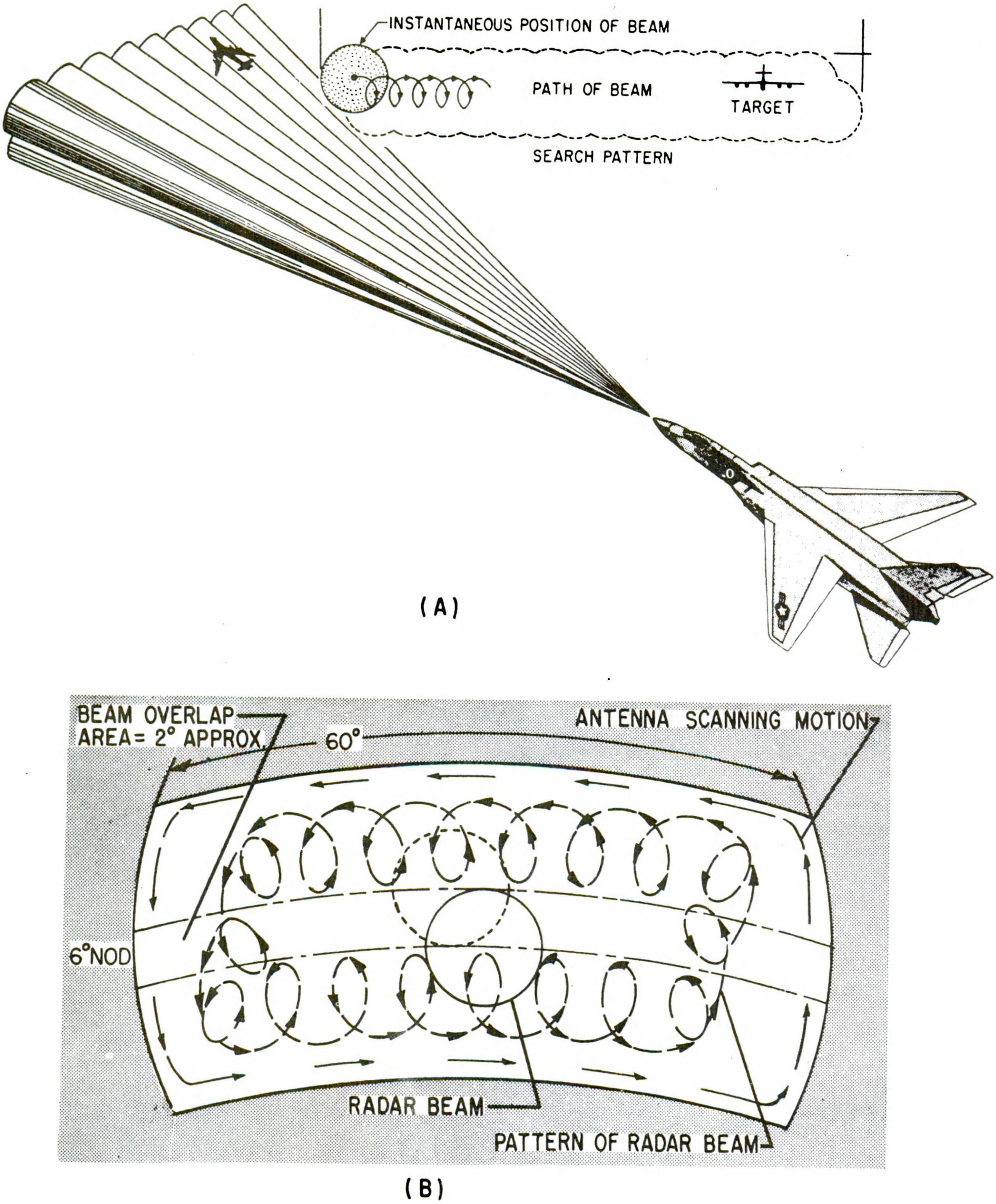

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Figure 8-4.—(A) Antenna scan pattern; (B) antenna coverage pattern.

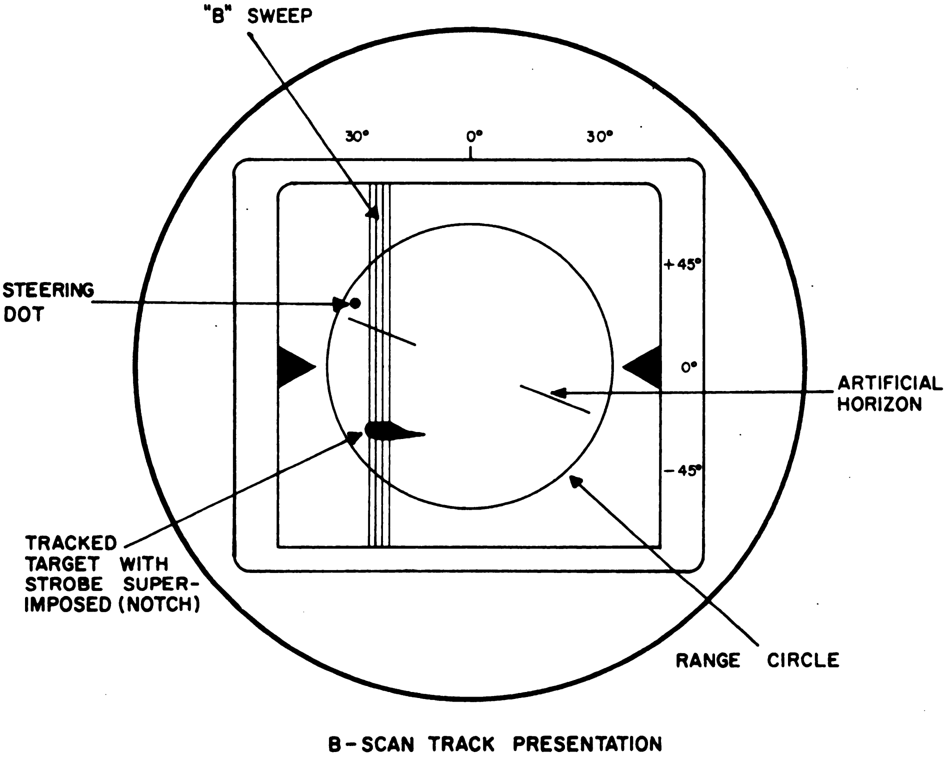
from zero to maximum range, depending on the range selected. For example, if the radar is operating in the 0- to 10,000-yard range, and a target appears at 5,000 yards, the acquisition marks may be moved to bracket the target by use of the range control.

The major display differences between automatic search and manual search are that the acquisition marks bracket and move with the B-trace, and the antenna is controllable in azimuth. All symbols that were present in automatic search, including the artificial horizon, are present in manual search. The horizon line still functions to indicate aircraft attitude. It should also be reasonable to expect to see no targets other than the ones which appear on the range sweep line since the antenna is no longer scanning.

FIRE CONTROL (LOCKON)

The lockon mode is a momentary mode of operation between manual track and automatic track. Some radars combine the previously described manual operations and the lockon mode into one mode called acquisition. Recall that acquisition is the period of time from the moment the antenna stops scanning until the radar locks on and begins to track the target automatically. However, in the trainer, manual track may be continued after lockon, if desired. Lockon is known to have been accomplished by a change in the B-scope presentation and the blanking of the PPI scope.

On the B-scope, the acquisition symbol is removed and replaced with a range strobe or notch superimposed on the target, as shown in figure 8-5. The artificial horizon remains as before. Note that there are two symbols present now that were not previously present. One of these is a small dot, called a steering dot. The purpose of the steering dot is to indicate antenna position which also presents target position with respect to the attacking aircraft. For a pure pursuit course the pilot need only maneuver the aircraft to cause the


"B" SWEEP
30°
0°
30°
+45°
0°
-45°
STEERING DOT
ARTIFICIAL HORIZON
TRACKED TARGET WITH STROBE SUPER-IMPOSED (NOTCH)
RANGE CIRCLE
B-SCAN TRACK PRESENTATION

222.124

Figure 8-5.—B-scan presentation after lockon.

steering dot to remain in the center of the scope. When the steering dot is in the center of the scope on a pure pursuit course, the target is dead ahead of the attacking aircraft.

The second symbol, which was not present in the previous modes, is a circle. This circle is called the range circle, and its diameter is proportional to range. Normally, lockon occurs at near maximum range which produces a range circle of maximum size. As the range between the attacking aircraft and the target decreases, the diameter of the circle also decreases, keeping the operator informed of the range to the target. In addition to these symbols, two other indications of range are presented at the time the radar locks on. A light, called the lockon light or acquisition light, is illuminated when the target has been acquired and lockon has, in fact, been accomplished. Range is also presented in digital form in a small window similar to the mileage counter of an automobile.

FIRE CONTROL (AUTOMATIC TRACK)

The automatic track submode of fire control results from the manual track mode upon release of the manual controls (range and azimuth). Remember, prior to automatic tracking the antenna had been manually controlled in both elevation and azimuth and the range strobe (notch) had been controlled by the range control. To initiate automatic tracking the operator releases the manual controls and the radar switches to automatic track. At this time the antenna is caused to track the target by the antenna servosystem error circuits.

Range tracking is accomplished in the range tracking circuits. Automatic tracking continues until one of three things occur. First, lockon will be lost if the attacking aircraft is closing on the target at a rate greater than 700 knots, or if an opening rate greater than 200 knots should occur. Second, the target will be lost and the radar will unlock if the target does not remain within the tracking window (antenna limits in azimuth and elevation). Finally, the target will be lost if the range exceeds maximum tracking range. Maximum range for tracking is 40,000 yards. At ranges beyond 40,000 yards the return echo will be too weak to maintain lockon. If unlock occurs, the system is automatically returned to automatic search and the cycle of manual track and acquisition must be repeated to regain target tracking.

FIRE CONTROL (BREAKAWAY)

The final submode of fire control is known as breakaway. This mode occurs automatically if the target is tracked to a range which would endanger the attacking aircraft. During automatic track of a target which has a decreasing range (attacking aircraft is closing on the target), the range circle is removed at the time the range to the target gets to 3,500 yards. In its place a large "X" is displayed which indicates time to break away from the attack. (See fig. 8-6.) Also, at this time the steering dot will move to a position on the scope to indicate the safe direction for the attacking aircraft to turn in order to execute a safe breakaway. In the illustration, minimum range has been reached and the breakaway X has appeared. The steering dot is presently positioned to the right and above center.

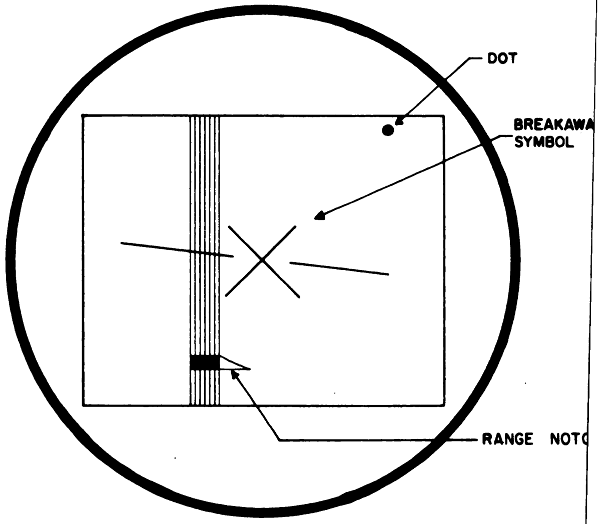


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Figure 8-6.—B-scan presentation breakaway indication.

BOMB DIRECTOR MODE

When bomb director mode of operation is selected, information is displayed on both PPI and B-scope indicators. In this mode the antenna automatically goes to sector scan, scanning a 60° arc, 30° to each side of dead ahead. Antenna elevation is manually controlled. The PPI scope has a depressed center which appears as a wedge shape scan on the indicator face, as shown in figure 8-7. The antenna is positioned in elevation so it will scan the surface of the earth during a bomb attack.

The target tracking range and azimuth strobes appear on each of the two indicators and are moved manually so the marks form a crosshair effect and are centered over the target to be tracked. Tracking is maintained manually in the bomb director mode. The B-scan presentation, which is expanded to five times that of the PPI, is used for precise aiming. The azimuth and range strobes are controllable from 0 to 80,000 yards, and, in azimuth, 25° to either side of center.

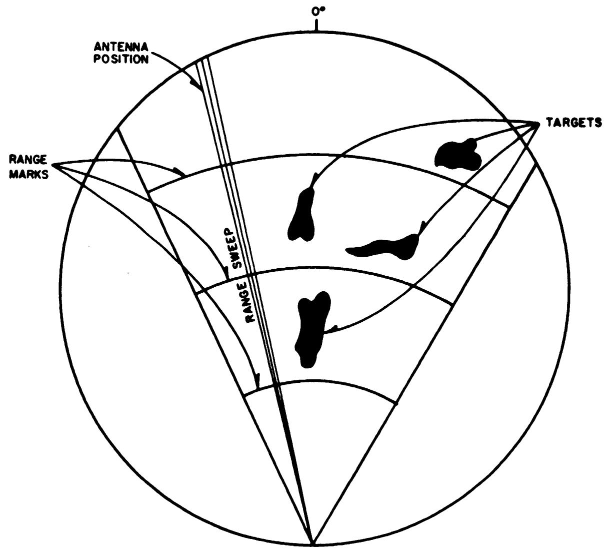

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Figure 8-7.—PPI presentation in bomb director mode.

THEORY OF OPERATION

We are now ready for a discussion of the trainer theory of operation. The discussion is at a block diagram level and avoids circuit tracing. Most of the circuits presented, typical of an operational radar, are described in other chapters of this manual.

SYNCHRONIZER

The synchronizer develops all timing signals required for proper operation of the radar in all modes. Functionally, the stages comprising the synchronizer are grouped according to the signals they develop, as shown in figure 8-8. Table 8-1 lists and describes the nature of these outputs. Inputs to the synchronizer are the ac operating power and the remote trigger from the transmitter.

Timing Signal Generation

The timing sequence of the synchronizer is initially controlled by a 1-kHz reference oscillator. The basic timing signal is developed by the reference oscillator and then coupled to the Schmitt trigger stage. The trigger stage produces sharply defined, stabilized, negative square waves which are differentiated in the output and then coupled to the emitter follower. The emitter follower provides isolation between the trigger stage and the delay and master trigger circuits. The purpose of the isolation is to prevent loading of the trigger stage. The output of the emitter follower is a series of negative pulses which have been clamped at ground potential and occur at a precise 1-kHz repetition rate. Note that these pulses have very sharp leading edges that correspond to system time zero, t_0.

From the basic trigger circuit, the timing pulses are coupled into the master trigger circuit which serves to increase pulse power. After the pulses are amplified, they are inverted to produce positive pulse trains and are again clamped at ground potential. These pulses, which are in coincidence with those of the basic trigger circuit, are used to maintain synchronization of the indicator, range tracking circuits, and target generator with the rest of the system.

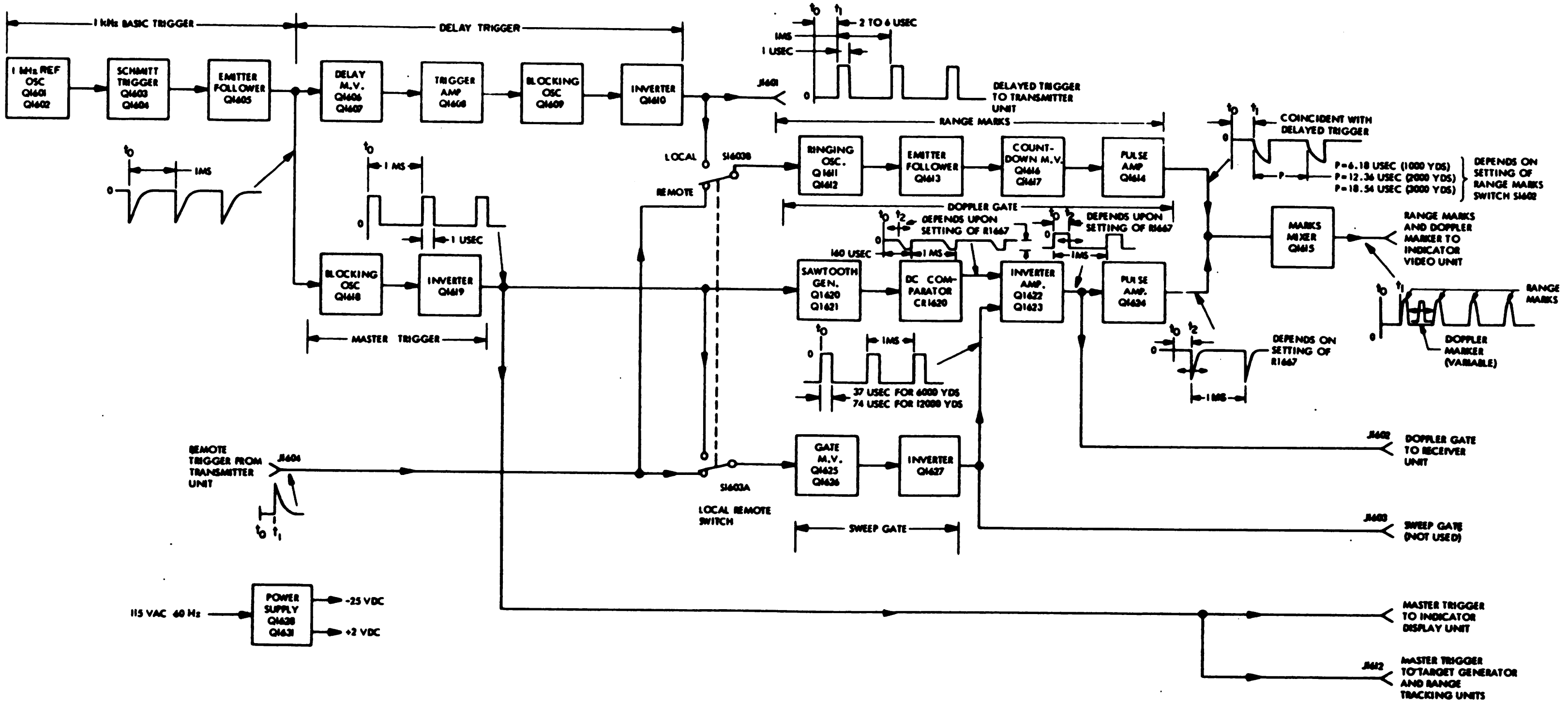

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Figure 8-8.—Synchronizer functional block diagram.

Table 8-1.—Synchronizer Signal Description and Function

Signal	Description and function
Master trigger	20-volt, positive, ground-clamped, 1- μsec pulses occurring at a repetition rate of 1-kHz. The leading edge of the master trigger pulses establishes time zero for the entire system. These pulses are applied directly to the indicator display (unit 1500) target generator (unit 1300) and range tracking (unit 1900) chassis to insure proper synchronization between the three.
Delayed trigger	20-volt, positive, ground-clamped, 1-μsec pulses occurring at a rate of 1-kHz. The leading edge of the delayed trigger pulses is adjustable in time over a range of 2 to 6-μsec after the master trigger pulses, and serve as a transmitter trigger pulse, allowing coincidence between the PPI sweeps and displayed target video to be adjusted to compensate for overall system delays.
Range marks	20.5-volt, positive, ground-clamped pulses occurring with an interpulse time of 6.18, 12.36 or 18.54 μsec depending upon the setting of the 1,000-, 2,000-, 3,000-yard range selector switch S1602. Timing is adjustable to be coincident with the leading edge of the master trigger pulse or the remote trigger pulse depending upon the position of the LOCAL-REMOTE switch S1603. Range marks are applied to the PPI scope in the 6,000- and 12,000-yard search modes of operation only.
Doppler gate	Variable width, 25-volt, negative pulses occurring at a 1-kHz rate, timed so leading edge develops at time zero. Leading edge serves as a trigger for the receiver unit STC circuit, and the variable trailing edge serves to trigger the receiver Doppler gate circuits. Trailing edge also is differentiated to form a Doppler marker pulse which is mixed and applied to the PPI with the range mark pulses.
Sweep gate	25-volt, positive, ground-clamped, square pulses 37 or 74 μsec in width, depending upon the setting of 6,000- 12,000-yard range selector switch S1604. Leading edge is coincident with time zero and pulse repetition rate is 1 kHz.

Referring again to figure 8-8, note the same basic trigger is also applied to the delay circuit. The purpose of this circuit is to produce pulses used to trigger the transmitter during the time the ynchronizer is controlling the PRF. The input ulses are applied to a delay multivibrator. The utput of this multivibrator is a positive going ulse train whose leading edges are coincident with he input, but whose trailing edges may be djusted (delayed) in a range from 2 to 6 μsec. The pulse train is first amplified in the trigger mplifier and inverted. The output of the trigger mplifier is a negative going pulse train, applied o a blocking oscillator. The blocking oscillator triggered by the positive swing (trailing edge) of the pulses applied. Since the trailing edges are adjustable, the time that the blocking oscillator is triggered may be varied. Also its output will be a positive going pulse train, whose leading edge may appear (in time) anywhere from 2 to 6 μsec later than the input time zero pulse. This is illustrated by the waveform at the output of the delay circuit.

Recall that range marks appeared on the PPI sweep at intervals of 1,000, 2,000, or 3,000 yards. To ensure that these marks appear at the correct time and indicate correct range on the sweep, the range marks circuit must be triggered at the time the transmitter fires. Note in the illustration that the range marks circuit may be triggered either by the delayed trigger or by the remote trigger from the transmitter. The selection of the trigger to be used is the function of the local-remote switch S1. Assuming the local-remote switch is in the local position, the range marks circuit will be triggered at the same time the transmitter is fired (using the output of the delay trigger circuit).

Generation of the range marks is initiated by the application of the delayed trigger pulse or remote trigger from the transmitter to a ringing oscillator. This oscillator produces a 162-kHz sinusoidal output which is coupled into an emitter follower and then to a countdown multivibrator. The operation of the countdown multivibrator is controlled by the range marks selector switch, which determines whether the marks are 1,000-, 2,000-, or 3,000-yard marks. The output of the circuit is shown as a pulse train in coincidence with the delayed or remote trigger. The time between pulses (P) is determined by the setting of the range marks switch. The output is next applied to a marks mixer where it is mixed with a Doppler marker and routed to the indicator.

The Doppler gate, which is required by the receiver for operation of the sensitivity time control circuit and receiver Doppler circuits, is developed by the Doppler and sweep gate circuits as shown in the illustration. When the local-remote switch is in the local position, timing of the Doppler gate circuit is controlled by the master trigger pulse, which is simultaneously coupled into the Doppler circuit sawtooth generator and the sweep gate multivibrator.

At time zero and with the local-remote switch in the local position, the gate multivibrator produces either a 37-microsecond (6,000-yard) or a 74-microsecond (12,000-yard) sweep gate pulse determined by the setting of the range selector switch. Simultaneously, the sawtooth generator of the Doppler gate circuit produces a negative sawtooth waveform which is applied to a dc comparator. However, only a portion of the sawtooth is passed by the comparator since its output is adjustable by a range gate delay control. This means that a measured delay is introduced and the comparator passes only a portion of the sawtooth. As a result the inverter amplifier develops a pulse whose leading edge is in coincidence with time zero and whose trailing edge is adjustable. This gate pulse is now applied to a pulse amplifier where it is differentiated and coupled to the marks mixer along with the range marks. The Doppler gate is also routed to the receiver where it is used to operate the STC and Doppler circuits. These circuits are described later.

TRANSMITTER

The transmitter generates RF pulses which are transmitted to the RF system. It consists of a trigger generator, modulator, magnetron, and associated power supplies. Figure 8-9 illustrates, in block diagram form, the transmitter unit. Inputs to the transmitter are the trigger from the synchronizer and 115 volts 60 Hz line voltage.

The trigger from the synchronizer is applied to the transmitter trigger generator as illustrated. The trigger generator consists of a blocking oscillator V1 and emitter follower V2, shown in the upper left corner of the illustration. When the transmitter is controlled by the synchronizer, V1 is synchronized to the system PRF by the delayed trigger from the output of the delay trigger circuit. The output of V1 is coupled to the cathode follower V2. The output of the trigger generator is then applied to the modulator switch tube.

As previously mentioned, the 11D13A has special features incorporated to permit operation of each of the major units independently. The transmitter may be operated alone because it has its own power supply and trigger generator. The blocking oscillator, when not synchronized by an external trigger, will free run and has an RC circuit which is adjustable to control the PRF between approximately 700 and 3,000 Hz. Thus, if the free running frequency is adjusted to 900 Hz when the PRF is controlled by the synchronizer, synchronization at 1,000 Hz is accomplished.

The output of the blocking oscillator is a sharp positive going spike, 2 μsec in duration. This pulse is developed across a transformer in the plate circuit of the blocking oscillator and is then used to trigger the switch tube (V3) in the modulator.

The modulator consists of a thyratron used as a switch, a pulse forming network Z1 and L1, and the pulse transformer T2. The operation of

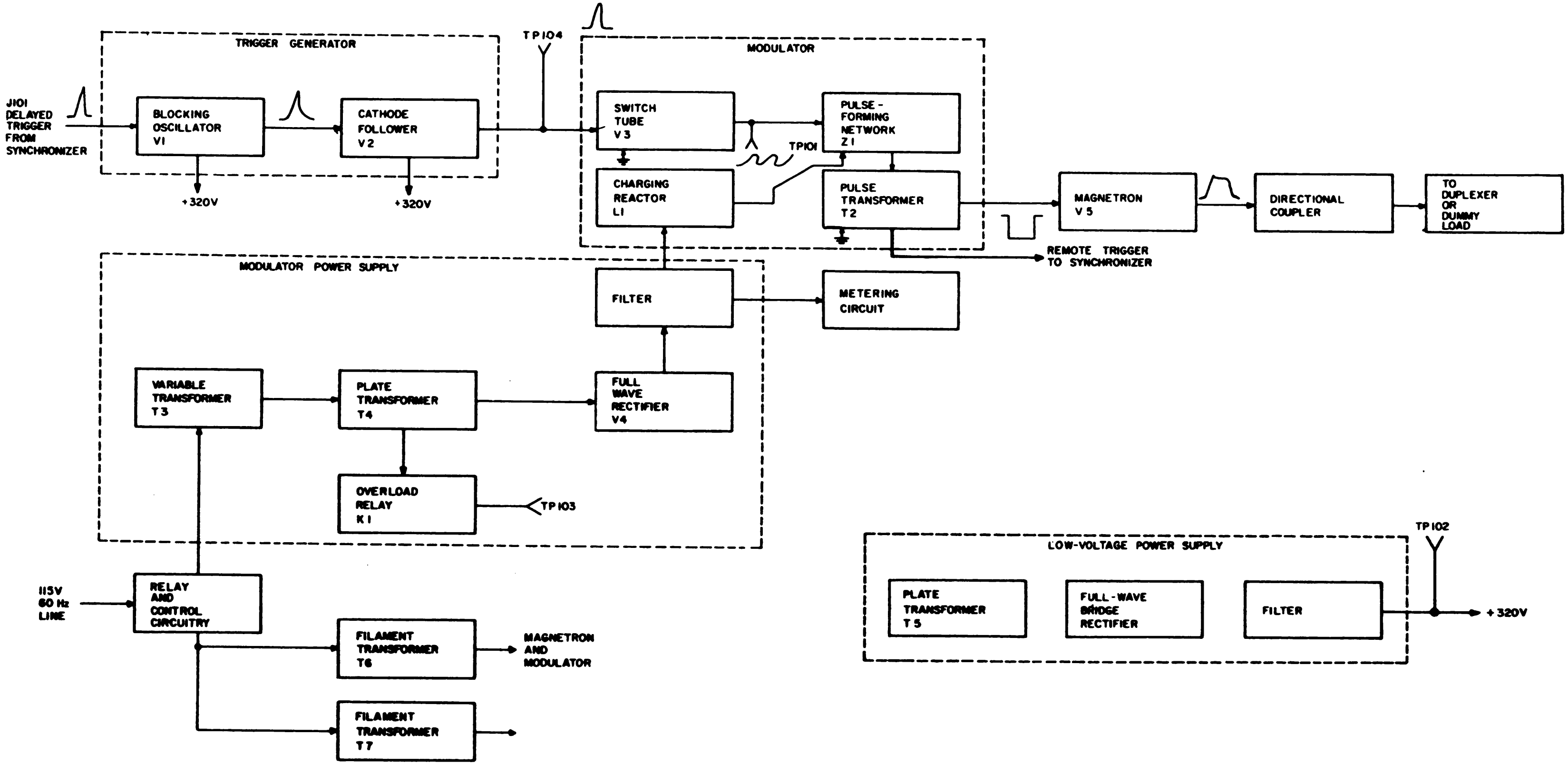

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Figure 8-9.—Transmitter block diagram.

the modulator is very similar to that described in Chapter 7 of this manual.

CAUTION: Voltages necessary to operate a magnetron transmitter-modulator in many radars are in the vicinity of 10,000 volts or more, and the technician must observe all safety precautions when working with or near such circuits.

Note in the illustration that the pulse transformer T2 provides the high-voltage pulse to trigger the magnetron and develops a remote trigger which is used in the synchronizer. The RF output pulse from the magnetron is passed to the directional coupler and then into the duplexer or a dummy load. If the RF energy is directed to the duplexer, it may then be sent to the antenna and radiated. If directed to the dummy load, all the energy is absorbed in the load and no radiation takes place.

Referring to the illustration, note that two power supplies are incorporated in the transmitter. These are a high-voltage power supply for the modulator, and a low-voltage power supply, which provides plate voltages for the trigger generator; and two filament transformers, which provide filament power to the tubes as indicated.

Included in the power circuits are relay and control circuitry. The purpose of the circuitry is the safety of the technician. It also prevents damage to the components in the high-voltage circuits. To safeguard the technician, a pair of microswitches removes the input power any time the cover of the transmitter is removed. This type switch is called a safety interlock, since to close the circuit the cover must be in place, automatically protecting the operator. Never disable these switches—to do so will endanger the life of any person working on the equipment. To prevent damage to the equipment, a 30-second thermal, time delay relay is incorporated to prevent application of power to the high-voltage sections prior to warm up. An overload relay K1 prevents damage to the equipment if a current overload should occur.

RECEIVER

The receiver accepts returned target echoes from the antenna and duplexer system and transforms them into video signals, which are then applied to the indicator display unit. A Doppler signal is also produced in the receiver, which is used to provide an audio signal indicating relative target speeds. This Doppler signal is a manufactured signal to indicate closing velocity and is not the same as a pulse Doppler receiver used in actual weapons systems. Recall that the Doppler (range gate) was developed in the synchronizer. Figure 8-10 illustrates the receiver unit in block diagram form and includes an IF-AFC mixer assembly, a sensitivity time control generator (STC), amplifiers for the IF, IAGC, AGC, video and audio, the Doppler circuit, an AFC circuit, and associated power supplies.

Inputs to the receiver are the RF signals from the duplexer, the delayed range gate from the synchronizer, and the 115-volt 60-Hz line voltage supply to the power supply.

Referring to the illustration, note that RF signals are applied to the IF-AFC mixer assembly in the upper left hand corner of the illustration. In the mixer, these signals are combined with the output of the local oscillator (V215). The purpose of the mixer is to produce the difference frequency (IF) signal. Two 30-MHz IF outputs are taken from the mixer assembly; one signal is passed to the IF amplifier, and the second is coupled into the AFC amplifier.

For training purposes, the receiver may also be operated as an independent unit. It has its own power supply and an RF signal may be introduced by use of a conventional signal generator.

The 30-MHz signal from the mixer is coupled into the IF amplifier which consists of a cascode input stage, five pentode amplifiers, and a detector. The IF signal is coupled into the amplifier through a double-tuned input transformer. The first two amplifiers, which form the cascode input (V901 and V902), provide a high gain, low noise output. The high signal-to-noise output of V902 is then fed to five identical amplifiers, V903 through V907. These amplifiers are stagger tuned to provide a 4-MHz bandwidth which is required by the receiver. The output of V907 is then coupled into a crystal diode detector where the video is detected.

The output of the detector is a video pulse, negative going, with a duration of 1 microsecond. This 1 microsecond video pulse is fed to one more stage of amplification in the video circuits, and

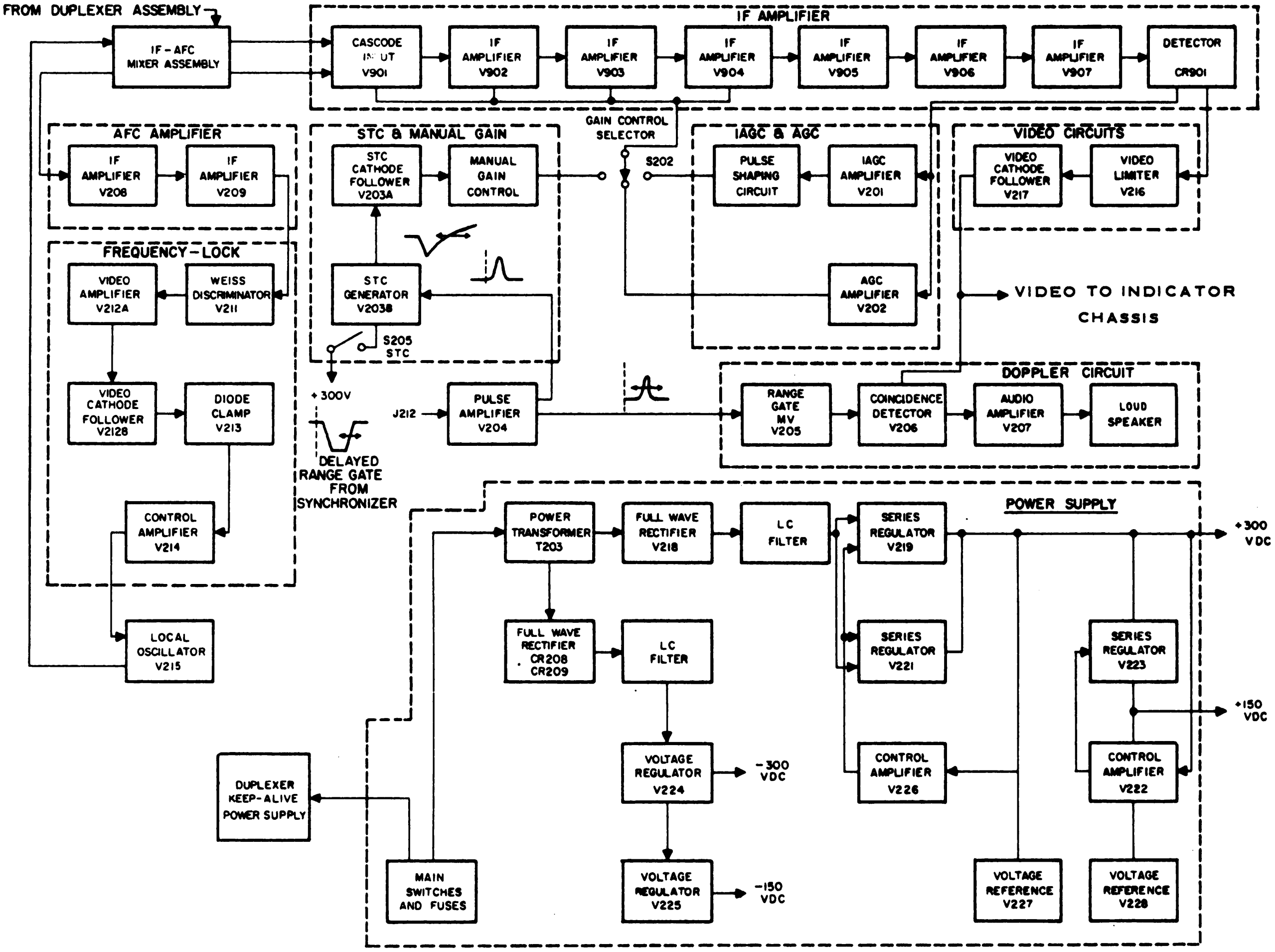

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Figure 8-10.—Receiver block diagram.

from here it is passed on to the indicator unit for presentation on the PPI and/or B-scope indicators. The same video pulse is also coupled into the instantaneous automatic gain control (IAGC) and automatic gain control (AGC) circuits where it functions to control the automatic gain of the receiver.

In figure 8-10 note that a three-position gain control selector switch (S202) is provided to select the type gain control desired. The three positions are IAGC, AGC, and manual gain. When manual gain has been selected, sensitivity time control may also be used. Whether or not this circuit is operational depends on actuation of the on-off STC switch (S205). The purpose of the STC switch is to eliminate the possibility of near targets being obscured. This is accomplished by reducing the gain of the receiver sharply at the instant the transmitter is pulsed, and then allowing the gain to rise to normal over a period of time. This period of time is determined by the setting of the STC control, and the gain rises at an exponential rate. The circuit consists of a pulse amplifier V204, STC generator V203B, and a cathode follower V203A. When the dc supply voltage is applied by means of the STC on-off switch, the leading edge of the positive range gate from the synchronizer is differentiated, amplified, and clipped in the plate circuit of V204, and used to trigger the STC generator. The leading edge of this pulse is in coincidence with the range gate pulse. Therefore, the leading edge of the exponential waveform produced by the generator will also coincide with the range gate pulse, as illustrated. The exponential rise period, which determines the duration of the STC pulse, is controlled by an RC time constant, and is adjustable. The output of the generator is coupled to the cathode follower and then applied to the gain function switch. The initial operating level of this STC circuit is set by the manual gain control.

DOPPLER CIRCUIT

The receiver system includes a Doppler circuit which is used to detect moving targets. The Doppler circuit consists of a range gate multivibrator V205, a coincidence detector V206, an audio amplifier V207, and a loud speaker. The multivibrator is a monostable flip-flop triggered by a pulse from pulse amplifier V204. Since this pulse is initiated by the trailing edge of the synchronizer delay range gate pulse, (which is variable), the output of the range gate multivibrator V205 is a 2-μsec pulse, which may be moved so that its position will coincide with any target within the range of the delayed range gate. The coincidence detector V206 will detect all signals from the video amplifier V217 which occur during the time the gate, generated by V205, is present at the coincidence detector. Any target present in the gate will vary in amplitude if it is moving in range. As the target increases or decreases in range, the video pulses appearing in the range gate will, over a period of time, produce a pulse train which will appear to be amplitude modulated. The modulation frequency will be a function of, and vary directly with, the velocity of the target. The output of V206 is a pulse train which is filtered, passing only the amplitude variations (modulation envelope caused by target movement) to the audio amplifier V207. The output of V207 is then applied to a speaker. An on-off switch is provided for this circuit to allow the operator to silence the Doppler tone if desired.

AFC CIRCUIT

The AFC circuit consists of two amplifiers (V208 and V209), a discriminator (V211), a video amplifier (V212), a clamping diode (V213), and a control amplifier (V214). The output of this circuit is used to vary the repeller plate voltage of the local oscillator (klystron) to maintain the IF (difference frequency) at 30 MHz. This is necessary since the receiver IF circuits are tuned to 30 MHz. The output of the IF-AFC crystal mixer is coupled to the AFC amplifier and amplified by both V208 and V209. The two amplifiers are also tuned to the system's 30-MHz IF.

The output of V209 is then applied to the discriminator V211. V211 is a frequency discriminating circuit which produces output pulses whose amplitude and polarity vary with the frequency shift of the klystron. When the frequency drift of the klystron is in a direction which causes the input to the discriminator to be less than 30-MHz, the output of the discriminator is positive; negative pulses are developed if the discriminator input is greater than 30-MHz. The discriminator is adjusted so the crossover point (point between plus and minus) of the output is 30.5-MHz. Refer to Chapter 7 for complete detailed description of an AFC circuit similar to this one.

INDICATOR

The indicator unit includes both the PPI and B-scope, which display all the information needed by a pilot to make a successful intercept attack on an airborne target, or a bombing attack on a surface target in a bombing mission.

Referring to figure 8-1, note the inputs to the indicator. The range strobe is an input from the range tracking unit; video and switching signals are inputs from the video unit, and necessary power inputs from the power supply.

The B-scope is a CRT with two guns incorporated in a single tube. These are called the A-gun and the B-gun. Each of the guns has an independent deflection system so that, in effect, the scope is two CRTs sharing a common viewing screen. In the following paragraphs the generation of the different displays produced by each of the guns is discussed.

A-Gun Display Generation

The A-gun is used to display the range circle, breakaway symbol, horizon line, and the steering dot. Since it is impossible to display all of these symbols at the same time, they must be displayed on a time-sharing basis. Each of the symbols is displayed for a controlled period of time, which is a function of the time-sharing gates.

The time-sharing gates, developed from a 500-hertz reference signal, determine the display sequence. The sequence of the symbols is as follows: range circle or breakaway symbol, horizon line, dot, and clamp.

The range circle is a Lissajous pattern generated by applying two sine waves, phased 90° apart, to the vertical and horizontal deflection plates of the CRT. Figure 8-11 illustrates how a circle is produced in this manner.

As can be seen in the illustration, a circle has been described by passing the electron beam from point-to-point as the two sine waves pass through these points. Note that the voltage waveforms applied to the two horizontal deflection plates are exact opposites, as are the waveforms applied to the vertical plates; but the pulse relationship between the waveforms on the vertical plates and those on the horizontal plates are 90° out of phase.

Remember, the electron beam is negatively charged, and that like charges repel and unlike charges attract. Starting at point 0 on both the vertical and horizontal plates, the left horizontal plate is at maximum positive and the right

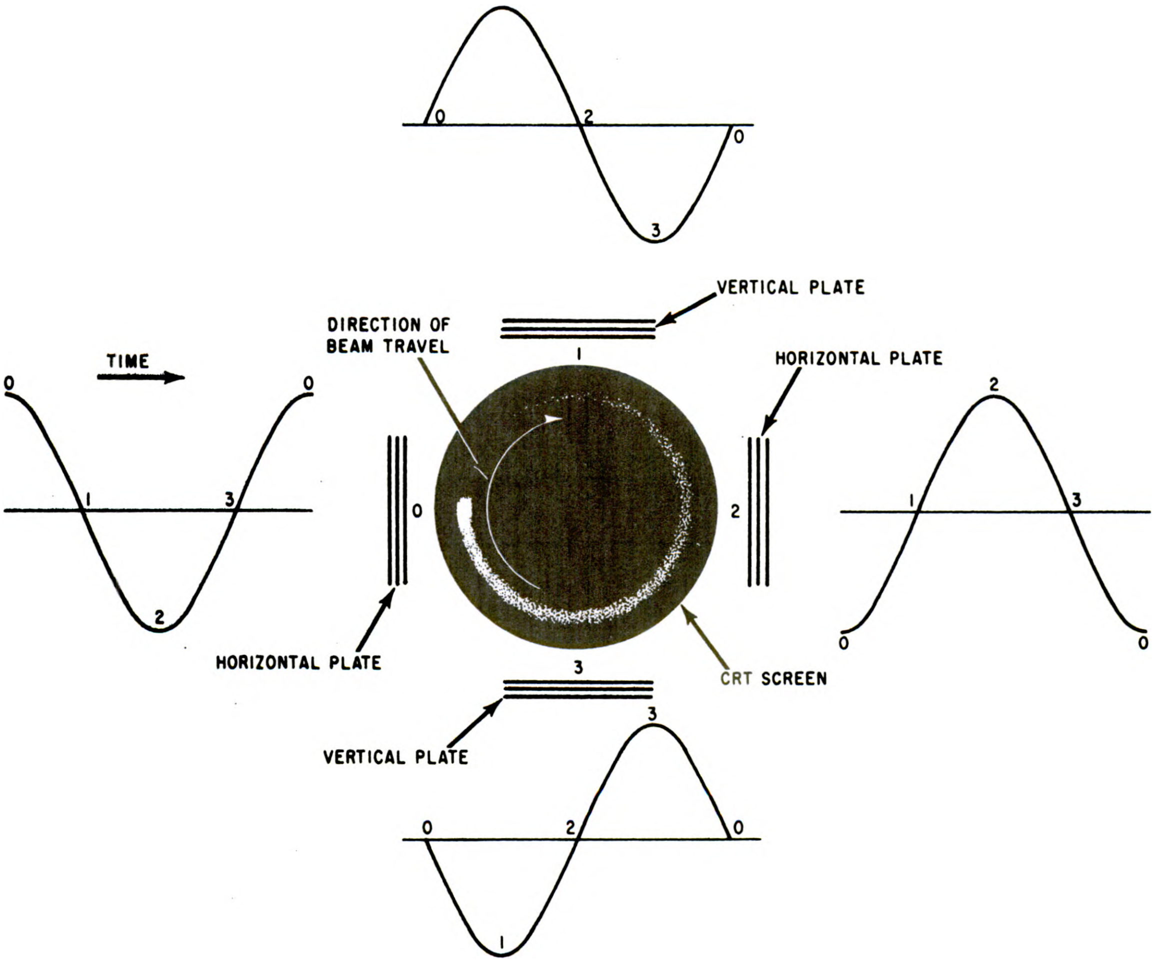

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Figure 8-11.—Generation of a circle on a CRT.

horizontal plate is at maximum negative. The effect of these two voltages is that the positive voltage attracts the electron beam, while the negative voltage repels the beam. This action will cause the beam to be displaced to the left on the screen, and the electrons in the beam striking the face of the tube will cause a bright spot.

If these voltages were to remain in this position, the spot would not move. However, as the sine waves continue in time (0 to 1), it can be seen that the voltage on each horizontal deflection plate moves toward zero; the voltage on the vertical deflection plates moves toward maximum—the top waveform going in the positive direction and the bottom waveform going in the negative direction. As time proceeds, the waveforms on the horizontal plates produce less and less influence on the beam, while those on the vertical plates produce an influence which is increasing. This causes the beam to be moved smoothly from point 0 to point 1, causing an arc to be written on the phosphor-coated screen of the CRT.

As the electron beam strikes the face of the tube, the phospher is caused to glow, leaving a trail of light behind it. This action continues on through points 2 and 3 and back to point 0, writing a complete circle on the CRT screen. If the frequency of these waveforms is very low, the electron beam would move around the circular path very slowly, and the trail or light would fade, as indicated in the illustration. Normally the frequency of the applied voltages is high, causing the beam to sweep over the face of the tube very fast, and one complete circle is written before the beginning of the circle can fade. Also, the circle is gated ON more than one time, and it appears to be continuous.

As previously mentioned, the A-gun is used to present not only the range circle, but also the horizon line, the breakaway X, and the steering dot. Each of these symbols is written on the face of the CRT one at a time, in a special sequence; and each is written over and over to present the particular symbol as continuous. This means that each symbol must share a portion of the entire time required to present them all. At this point refer to figure 8-12, which illustrates, in block diagram form, how this timing is accomplished.

Note the block labeled 500-Hz oscillator in the upper left corner of figure 8-12. This oscillator has two outputs—one is a 500-Hz reference signal, and the other is a 500-Hz synchronizing signal. The sync signal is applied to the gate multivibrator, A1502. The reference signal is applied to the amplifier gate generator A1503, pin 5 of J1522, range circle generator A1506, and breakaway generator A1505.

The range circle generator output is two sine waves, which are 90° out of phase. The signal from pin 7 has been shifted by −45° and the signal from pin 12 has been shifted by +45°. The ±45° shift is in respect to the input 500-Hz reference signal. Note also that range voltage is an input to the circle generator; this voltage determines the size of the range circle on the indicator. The two potentiometers R1515 and R1516 are used to balance the dc level in the output. The two output signals are then applied to relay K1501 and are used as inputs to the vertical and horizontal circle gates.

When the range circle is to be presented on the indicator, the sine waves must be gated through the vertical and horizontal gates. The gates used for this purpose are generated in the gate multivibrator, A1502. The circle gate is an 8-millisecond negative square wave from the gate multivibrator (pin 18), which is applied to the vertical and horizontal gates. The outputs of these two units are the vertical and horizontal deflection voltages for the range circle. The two deflection voltages are applied to the A-gun driver and deflection amplifier circuits, and are then placed on the vertical and horizontal deflection plates of the A-gun. Although the deflection voltages are applied to the deflection plates of the CRT, the circle would not appear unless the tube is conducting. In order for this to occur, an unblanking pulse must be applied at the same time. Note in the upper right hand corner of figure 8-12, a positive 50-volt pulse train unblanking waveform is indicated. The portion indicated by the arrow is the unblanking pulse for the range circle. The circle is written twice each time the circle unblanking gate appears. The complete cycle time required to present all of the symbols is

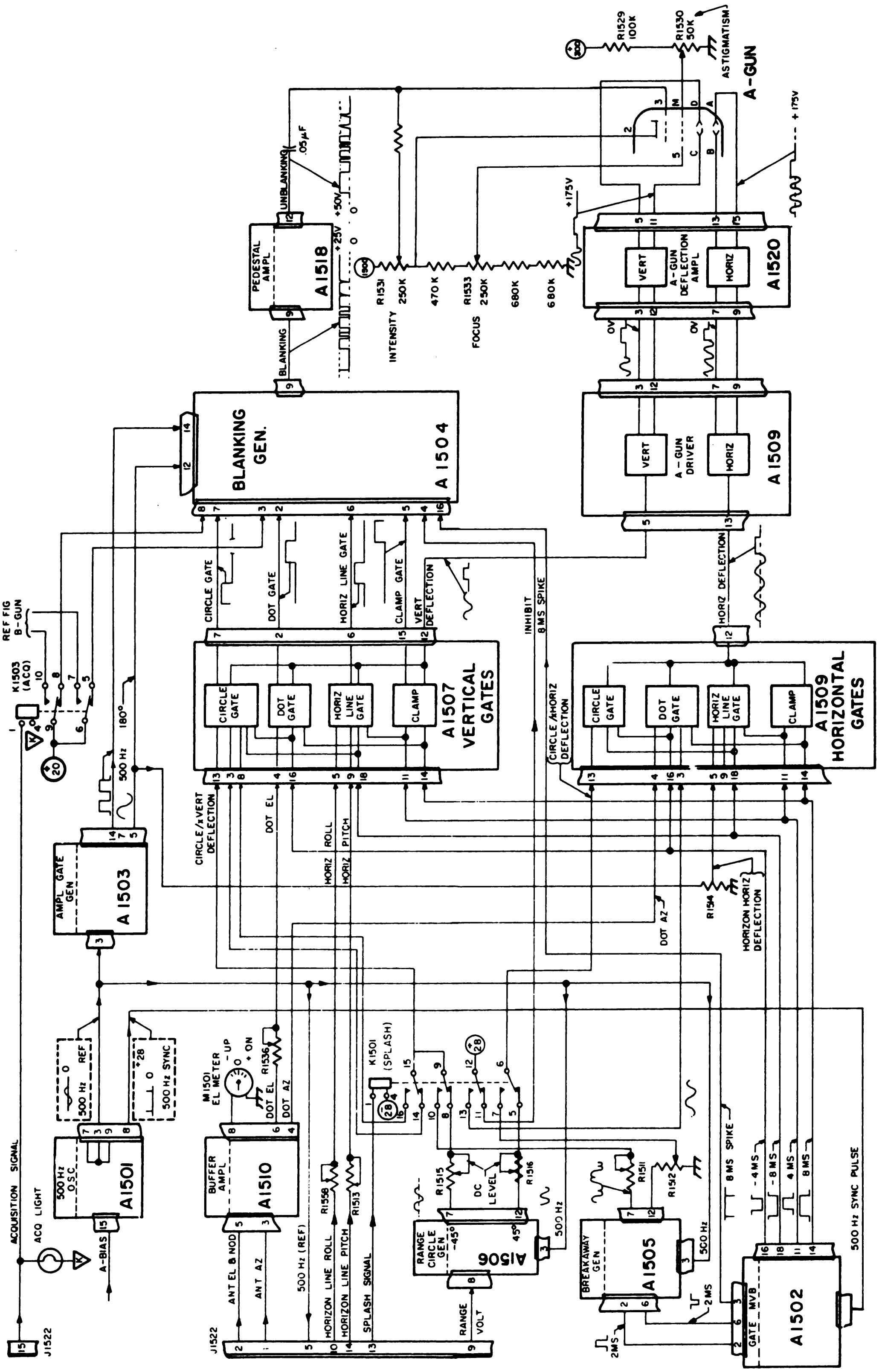

Figure 8-12.—A-gun block diagram.

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shown as 16 milliseconds (fig. 8-13). Line 1 shows the 500-Hz reference signal, and below this are the gates and waveforms for each of the symbols illustrated in their proper time relation.

Remember, the range circle and the breakaway X are not presented at the same time; either one or the other is written on the scope, using the same time period. To switch from the range circle to the breakaway X, relay K1501 (fig. 8-12) is energized by the signal shown as the splash signal. The splash signal is an input at pin 13 of J1522.

In the timing diagram (fig. 8-13), lines 2 through 5 show the timing gates, including a gate called clamp timing. The purpose of the clamp is to maintain the bias level on the tube to control the intensity of the symbols as they are gated on at the beginning of each cycle; intensity is initially set by R1531. Note that the bias for the CRT is provided by the voltage divider network between ground and the negative 1500 volts. Focus is controlled by focus control R1533 and astigmatism control R1530.

Recall that the position of the dot is an indication of the antenna position and is therefore a part of the horizontal and vertical deflection signal. The voltages used to position the dot are outputs of the buffer amplifier A1510 (pins 6 and 4). Also, recall that the horizon line will indicate to the pilot the attitude of the aircraft. This is a function of the stabilization circuitry, which in an actual system includes the vertical gyro. These inputs are shown as horizon roll and pitch signals applied to the vertical horizon line gate. These inputs become part of the vertical deflection voltages applied to the CRT and cause the horizon to follow the outputs of the stabilization circuits orienting the position of the horizon with that of the aircraft.

Two items shown in figure 8-12 are the acquisition light in the upper left hand corner and a meter used to indicate the position of the antenna shown just to the right of the buffer amplifier. To illuminate the acquisition light, an acquisition signal is applied to the acquisition relay K1503 via pin 15 of J1522. This light remains illuminated as long as the radar is locked on the target and is tracking.

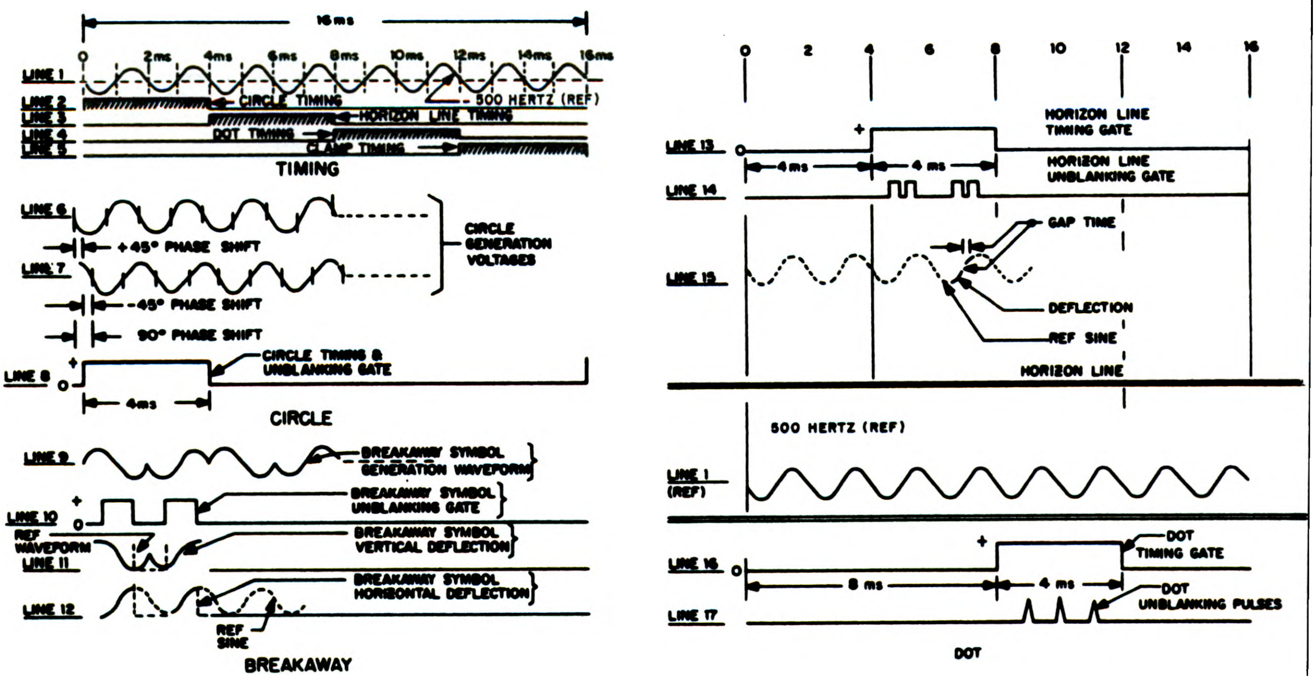

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Figure 8-13.—A-gun timing diagram.

B-Gun Display Generation

The B-gun is used to display the range sweep line, acquisition symbol, and target video. The range sweep line and acquisition symbol are displayed on a time-shared basis. The video is the result of intensity modulation of the electron beam as it sweeps in range. The sequence of the display is the range sweep line followed by the acquisition symbol. In the following paragraphs, refer to figure 8-14 which is a block diagram of the B-gun, and to figure 8-15, the B-gun timing diagram.

The signals required to generate and display the range sweep line are as follows: a sawtooth of voltage applied to the vertical deflection plates, an azimuth position voltage applied to the horizontal deflection plates, and an unblanking gate applied to the cathode of the CRT.

In figure 8-14, in the upper left corner, a trigger from the system (or an internal trigger) is applied to the range sweep generator through S1501 and K1502. If K1502 is energized, a delay trigger is used to start the B-scope range sweep generator. The outputs of the range sweep generator A1511 are a range sweep sawtooth and a range gate, which start at the time the trigger is applied. See figure 8-15, lines 1, 2, and 3. Duration of the range sweep gate and the slope of the sweep sawtooth are determined by the range switch K1502. These different ranges are shown superimposed in lines 2 and 3 of figure 8-15. In addition, the range sweep generator provides unblanking and time for the PPI scope. When K1502 is energized, the trigger applied to the range sweep generator comes from the delayed sweep generator A1512.

Inputs to the delayed sweep generator are the system trigger (or internal trigger) and range voltage, which is a dc control voltage signal. The output is a trigger which has a delay with respect to the input and is controlled by the input dc control signal. This output is shown in figure 8-15, line 4. The resultant range sweep voltage is then applied to the B-gun deflection amplifier A1519 and then to the B-gun vertical deflection plates. (See fig. 8-14.) Unblanking for the range sweep display is obtained by applying the range sweep gate, through the pedestal amplifier A1518, to the B-gun cathode. The horizontal position of the B-sweep is controlled by an input signal applied through K1502 (pins 5 to 6 or 7 to 6), to the horizontal switch A1517, to B-gun deflection amplifier A1519, then to the B-gun horizontal deflection plates. This positioning signal originates in the antenna sweep circuits and is applied to the buffer amplifier A1510. The output of the buffer amplifier is at pin 9 during normal sweep and is at pin 12 during expanded sweep.

Time sharing for the acquisition display is initiated by the range gate, which is applied to the acquisition symbol generator at pin 2 of A1514. The trailing edge of the range gate is used to start the generator. Other inputs required for the display include a 20-kHz sine wave from the 20-kHz oscillator A1515 (pin 9), which is applied to pin 9 of the acquisition symbol generator and used to determine the length of the symbol, and a 20-kHz square wave intensity signal from oscillator A1515. The intensity signals are shown as an output from pin 7 of the oscillator and as an input to the 10-kHz multivibrator pin 7. The output of this multivibrator is a 20-kHz intensity pulse taken from pin 5 and applied to the acquisition symbol generator pin 5. These pulses are gated through the symbol generator and are an output at pin 7. From here they are applied to the grid (pin 7) of the video mixer V1504. From the video mixer, the pulses are sent to the video amplifier V1505 and applied to the grid (pin 10) of the CRT. These same intensity pulses are also applied to the pedestal amplifier and 1-kHz multivibrator A1518 as the acquisition symbol unblanking signal. This input is at pin 3 of A1518 and is the B-gun unblanking pulse (pin 5). From here it is applied to the cathode of the CRT to unblank the tube during the time the vertical and horizontal signals for the acquisition symbol are present on the deflection plates of the CRT.

Inputs and outputs of the acquisition symbol generator are shown in their time relation in figure 8-15. Line 10 of the figure shows the portion of the 20-kHz sine wave which is actually displayed as the two vertical lines that make up the acquisition symbol. Line 11 shows the waveform which is used to space the lines in the horizontal.

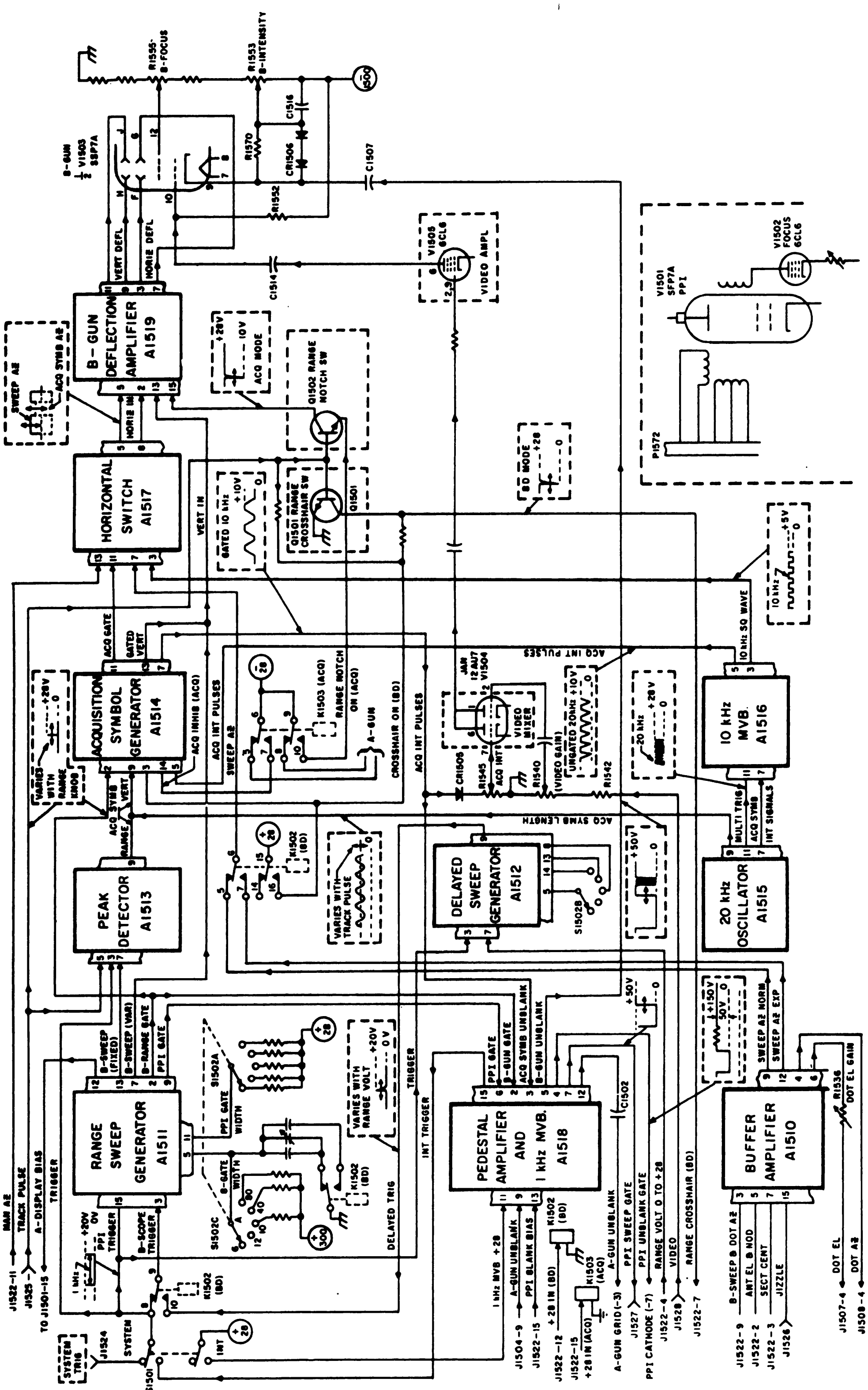

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Figure 8-14.—B-gun display generation block diagram.

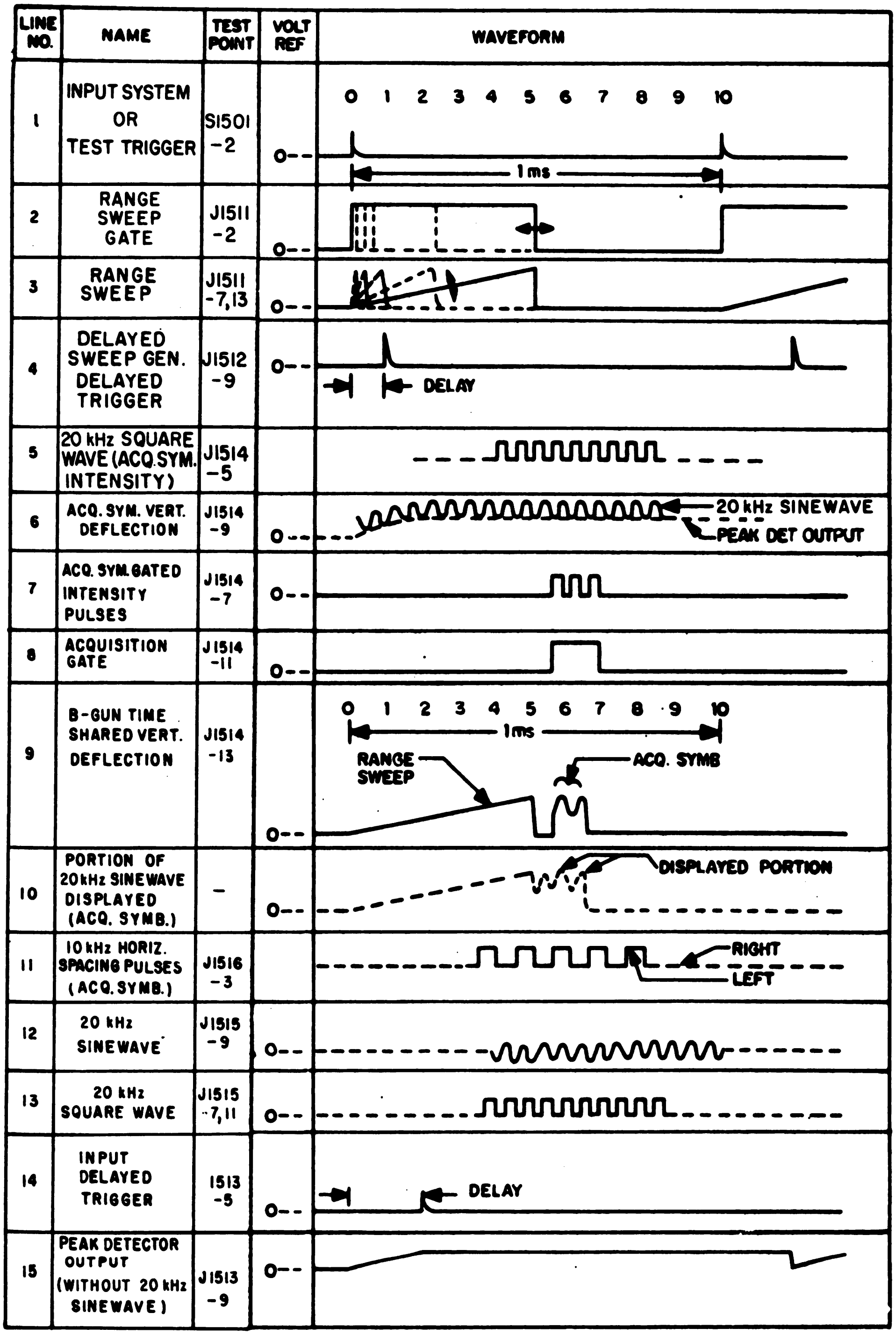

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Figure 8-15.—B-gun timing diagram.

Figure 8-16 illustrates how these signals are applied in respect to the symbol which is generated.

INDICATOR VIDEO UNIT

The indicator video unit is the system's interconnection and control center. It contains the computational antenna (antenna position servo which generates the signals that the actual antenna follows) and scan pattern generator. It also generates the PPI sweep and deflection signals, and processes and amplifies all video signals for both of the indicator displays. Most signals of the system are interconnected through the video unit as illustrated in figure 8-1.

Mode Switching

Control of the system is initially dependent upon the scan control switch, S1405. (See fig. 8-17.) This switch has two positions (PPI and SECTOR). When the switch is in PPI, the antenna is caused to scan 360°; the rpm of the scan may be automatic at 6 rpm or may be manually controlled by S1404, as previously described. PPI position is selected for normal radar search. With the scan switch in the SECTOR position, either fire control (FC) or bomb director (BD) operation may be selected. To select either FC or BD, a separate switch, S1406 (FC-BD switch) is provided. In the FC position, a 6° nod is introduced by the nod cam S1402 through the closed contacts of K1403. For the BD mode of operation, an azimuth mark signal is produced by the azimuth mark cam S1403, and sector center is controllable through use of sector center control R1443. Other controls are the azimuth, elevation, and range controls. These controls operate to transfer antenna control to manual, and also allow for positioning of the acquisition symbol and range and azimuth strobes.

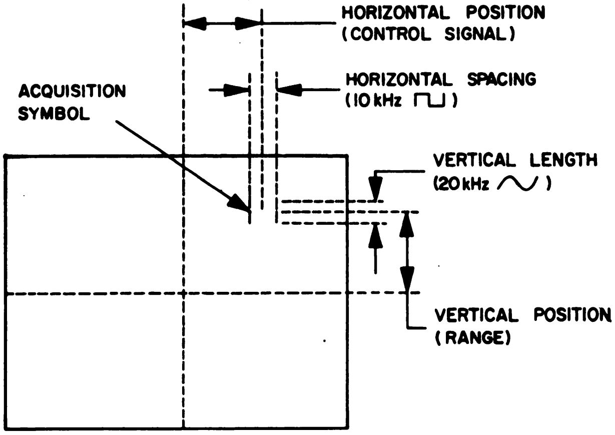

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Figure 8-16.—Acquisition symbol generation.

Selection of the bomb director mode disables the action switch of the azimuth and range potentiometers, and the nod signal. At the same time, the azimuth mark signal is fed into the video circuits. The PPI sweep is doubled and the center is depressed one radius; the expanded sweep circuits for the indicators are energized, and sector center control is removed, at which time azimuth mark control is substituted.

Selection of the fire control mode allows relays K1401, K1402, and K1403 to be operational, which control the sequencing in the FC mode. During FC search operation, these relays are deenergized and the radar operates with a 60° sector scan, a steerable sector center, and a 6° nod. The acquisition symbol is presented along with the B-scan, and is controllable in both range and azimuth, and the antenna is controllable in elevation. When the action switch is depressed, K1404 and K1403 are energized, transferring the azimuth control of the antenna and the display to manual operation and, at the same time, disabling the nod circuit. By movement of the range, azimuth, and elevation controls the target is brought into coincidence with the range track gate. When this occurs, the acquisition mode is actuated energizing K1402 and K1403. This operation is now manual track and the position of the track gate is controlled from the three previously mentioned position controls. The acquisition symbol is replaced by a range notch and the PPI scope is disabled.

Upon release of the action switches, K1401 is deenergized, which permits the tracking error signals to control the position of the antenna, maintaining automatic tracking of the target. If loss of the target occurs, the tracking signal from the track chassis disappears, and the system is placed in automatic search by deenergized relays K1402 and K1403.

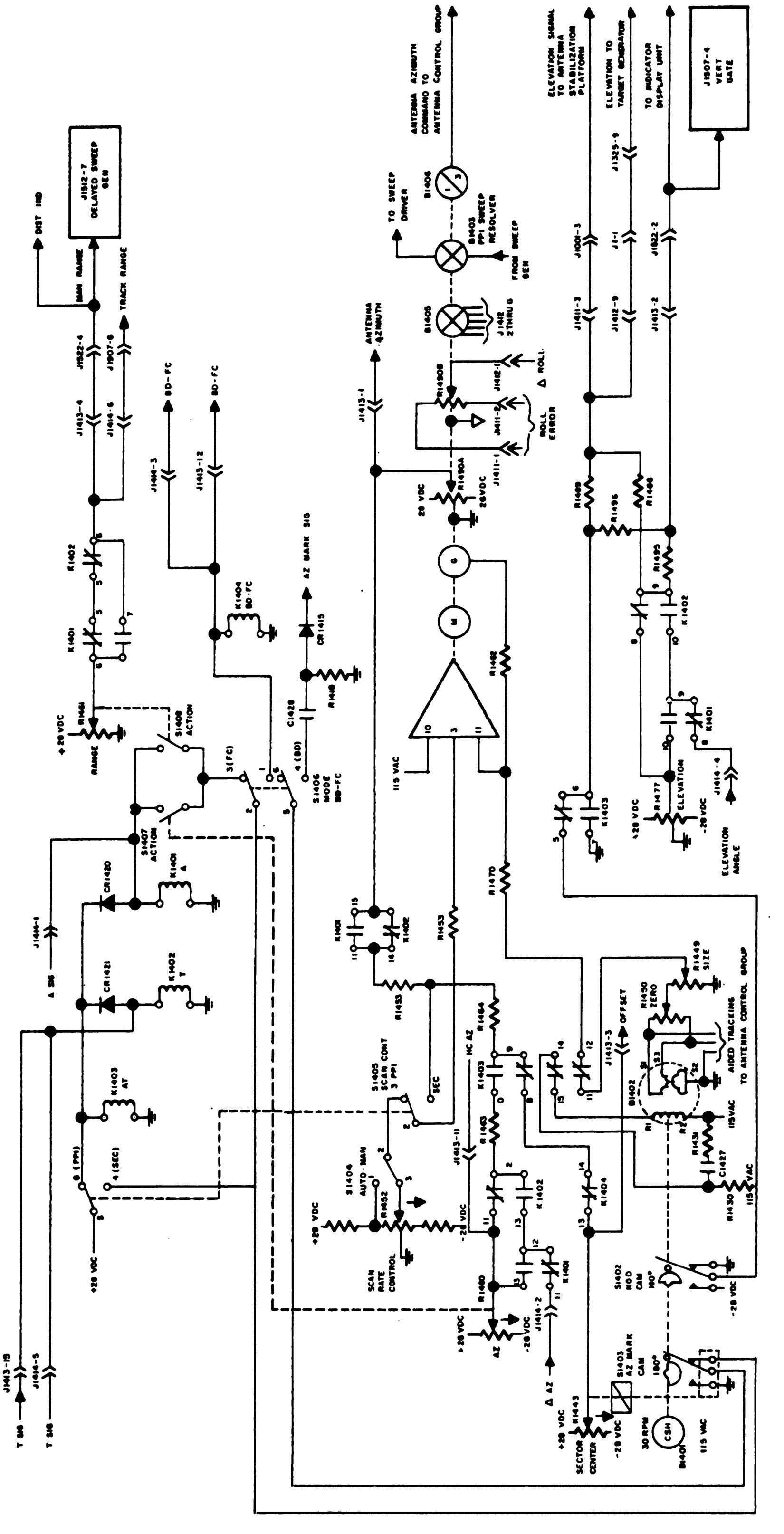

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Figure 8-17.—Indicator video unit simplified schematic.

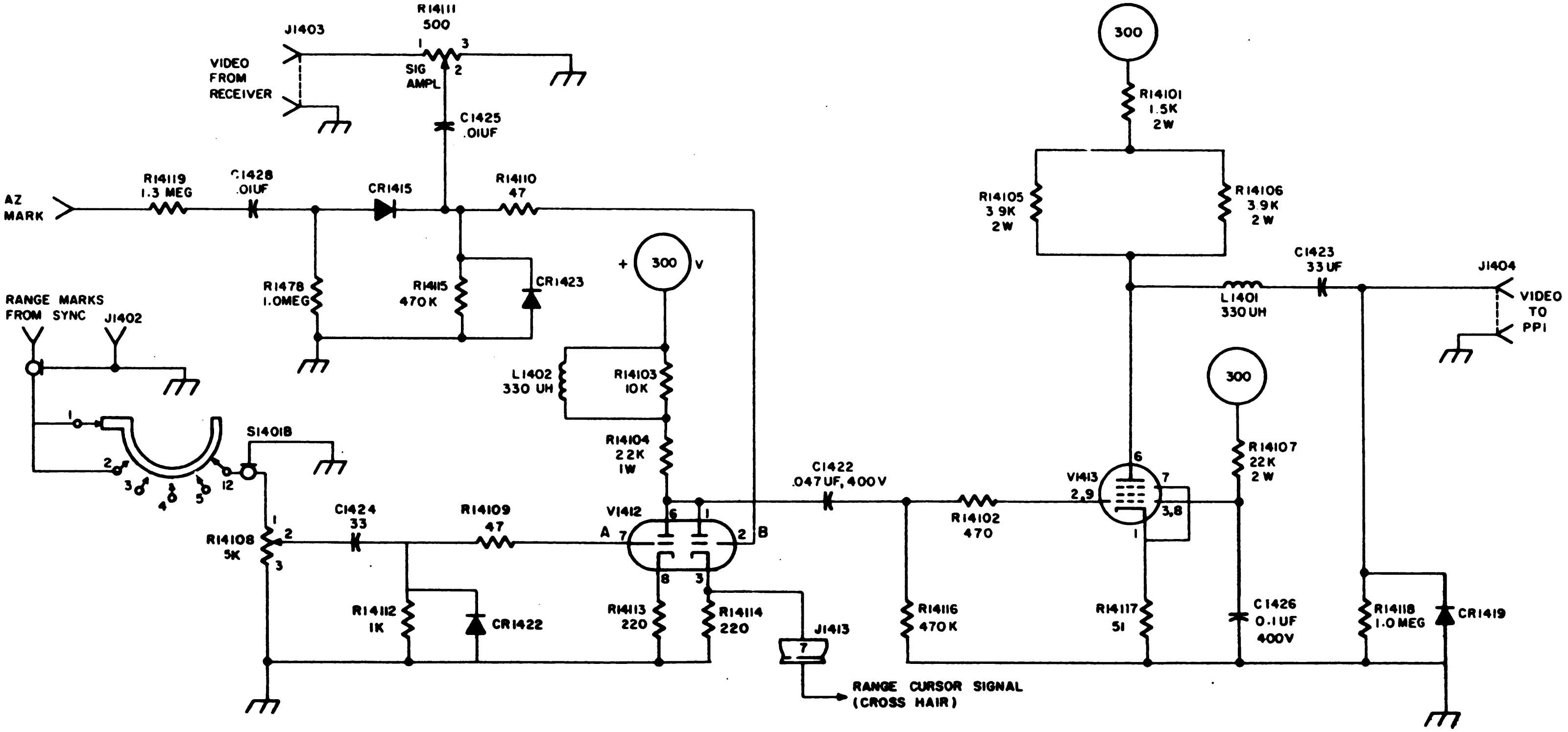

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Figure 8-18.—Video amplifier section.

Scan Pattern Generator and Antenna Position Servo

In the center of figure 8-17, the scan pattern generator is illustrated. The sector-scan patterns of BD and FC are generated by a 60-Hz resolver (B1402) driven by a 30-rpm constant speed motor (B1401). The sine wave output of the resolver is used as the basic scan pattern signal, and it is to this signal position that the nod and azimuth mark cams are aligned. The azimuth mark cam is set to just before the 180° point of the pattern, and the nod cam is set to just before the 90° position of the pattern.

There are actually two antennas in the system; one is the actual RF transmitting antenna, which is mounted on the antenna stabilization platform. The other is called a computational antenna, which the true RF antenna follows. The computational antenna is a conventional position-following servo as described in Chapter 3 of this manual. The scan-pattern signal is fed into a servoamplifier where it is compared with a chopped and amplified dc input from the antenna position potentiometer R1490. The error signal drives the antenna position servo to follow the scan pattern generator.

Video Amplifier Section

The video amplifier section is simply a mixer stage for the range marks, azimuth mark and video, and the range crosshair. Referring to figure 8-18, note that tube V1412 (A and B) is the mixer and tube V1413 is the amplifier. Range marks from the synchronizer are injected at grid pin 7 of the mixer (V1412). (This is only when the 6,000- and 12,000-yard ranges are selected.) The size of the marks is controlled by R14108, the range marks amplitude potentiometer. The azimuth mark, during bomb director operation, and the receiver video are injected at grid pin 2 of V1412. Receiver video is controlled by the video amplitude potentiometer R14111.

The range crosshair is applied to the mixer tube at the cathode of section B. Since this tube is a dual triode with its plates tied together, all of the signals are mixed at the plates. The amplifier V1413 then amplifies the entire signal. The output, which is at a 60-volt level, is then passed to the indicator display unit for use on the PPI and for further signal addition for B-scope video signals.

Azimuth Marks Generator

The azimuth marks generator (fig. 8-19) produces an azimuth mark on the PPI scope that

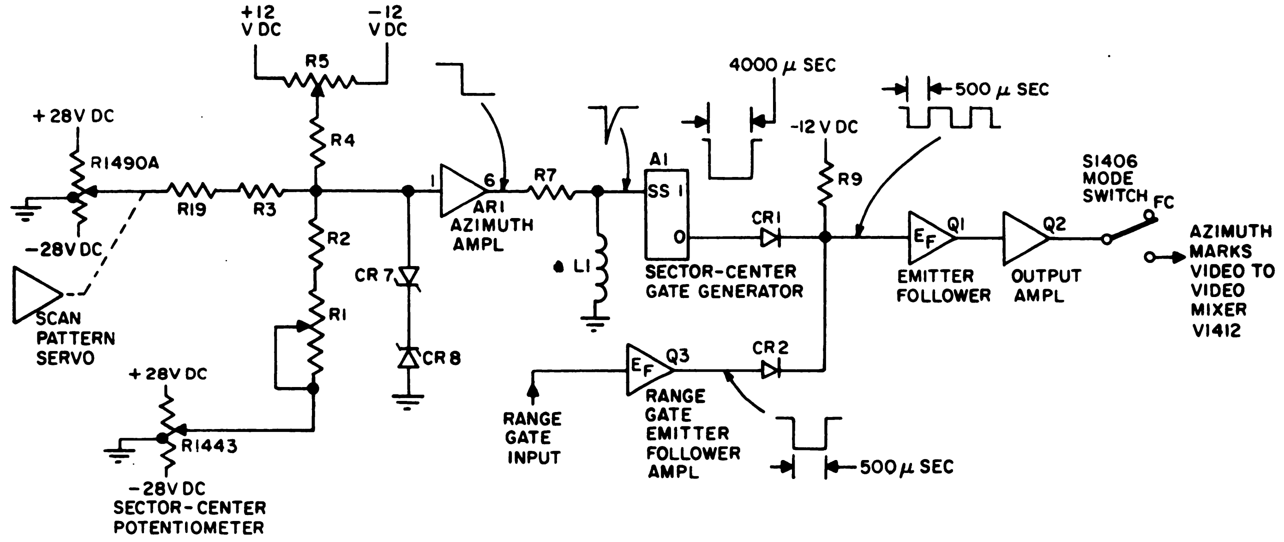

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Figure 8-19.—Azimuth marks generator.

marks the center of the sector-scan when operating in bomb director mode. Also, the output of this generator produces the vertical portion of the crosshairs on the B-scope. Two input signals are applied to the generator; one is taken from the servo potentiometer R1490A, which is a voltage that sweeps above and below zero and represents the sector-scanning of the antenna.

The second input is a dc voltage taken from the servo potentiometer R1443, which represents the center of the sector being scanned by the antenna.

Both voltages are summed in a summing network formed by fixed resistors R19, R3, R2, and R4, and potentiometers R1 and R5. Potentiometer R1 adjusts the amplitude of the sector-center input voltage and R5 adds an offset voltage to the sum of the input of AR1 to adjust the azimuth marks on the scope. A full wave limiter, Zener diodes CR7 and CR8, limits the input to AR1 to prevent overdriving the amplifier. As the antenna scans from right to left, the input from azimuth potentiometer R1490A becomes progressively less positive. As the sum of the inputs are fed to AR1, its output remains at some positive level. As the antenna reaches sector-center, the sum of the sector-center voltage from R1443 and azimuth voltage from R1490A equates zero or slightly negative; this causes the output of AR1 to be negative. The output will remain negative until the antenna reaches sector-center on its left to right scan; at this time it will again swing positive. Resistor R7 and inductor L1 form an RL differentiator, which shapes the output of AR1 into a sharp negative pulse used to trigger sector-center gate generator A1.

Sector-center gate generator A1 is a single shot (monostable) multivibrator responding only to negative input triggers. Since a negative input trigger is only generated when the antenna scans from right to left, A1 generates a scan gate only when the antenna scans from left to right. External RC components connected to A1 cause the circuit to generate a 4,000-microsecond negative gate when it is triggered. This negative 4,000-microsecond gate is applied as one input of a two input AND gate consisting of diodes CR1, CR2, and resistor R9. A 500-microsecond negative range gate input is passed through emitter follower Q3, which scales down the amplitude to a value required by the mark generator. Diode CR2, the second input of the AND gate, receives the negative range gate.

When the anodes of AND gate diodes CR1 and CR2 are both negative, the input to Q1 is also negative. Since the sector-center gate is four times as wide as the range gate, as many as four range gates pulses could be passed through the AND gate. The output pulses of the AND gate are the azimuth mark video pulses, which produce the azimuth mark on the center of the PPI sector scan and the B-scope. Emitter follower amplifier Q1 couples the output of the AND gate to output amplifier Q2, which feeds the mark video pulses through MODE switch S1406 in the bomb director position to video mixer tube V1412.

RANGE TRACKING UNIT

The range tracking unit allows the radar to track a target in range; and, if the input target video is applied from the target generator, it also develops antenna azimuth and elevation signals. These error voltages, applied to the antenna position servo and stabilization platform systems, allow the radar to track the target in angle (azimuth and elevation) as well as in range. The tracking unit tracks the target in range by generation of a range strobe (gate) and positioning the strobe in time (range) so that it coincides with the range of the target. After radar lockon, range tracking is accomplished by automatically and continuously adjusting the time of the range strobe, as the target changes range.

Angle tracking error signals are derived from the amplitude modulation on the target video pulses. The amplitude modulation is detected, and the phase of the detected signal is compared in a phase sensitive circuit with a reference signal. A dc error voltage is developed according to the phase difference, and is used to represent the antenna tracking error; this voltage is then applied to the antenna position servo in the indicator unit and to the antenna servosystem. Figure 8-20 illustrates, in block diagram form, the range tracking unit.

Range strobe pulses, which are 2-μsec in duration, are generated at the system trigger rate. The input for the system trigger is at J1905 on the illustration. This trigger is first inverted across Q1921, and then applied to a sweep gate, which

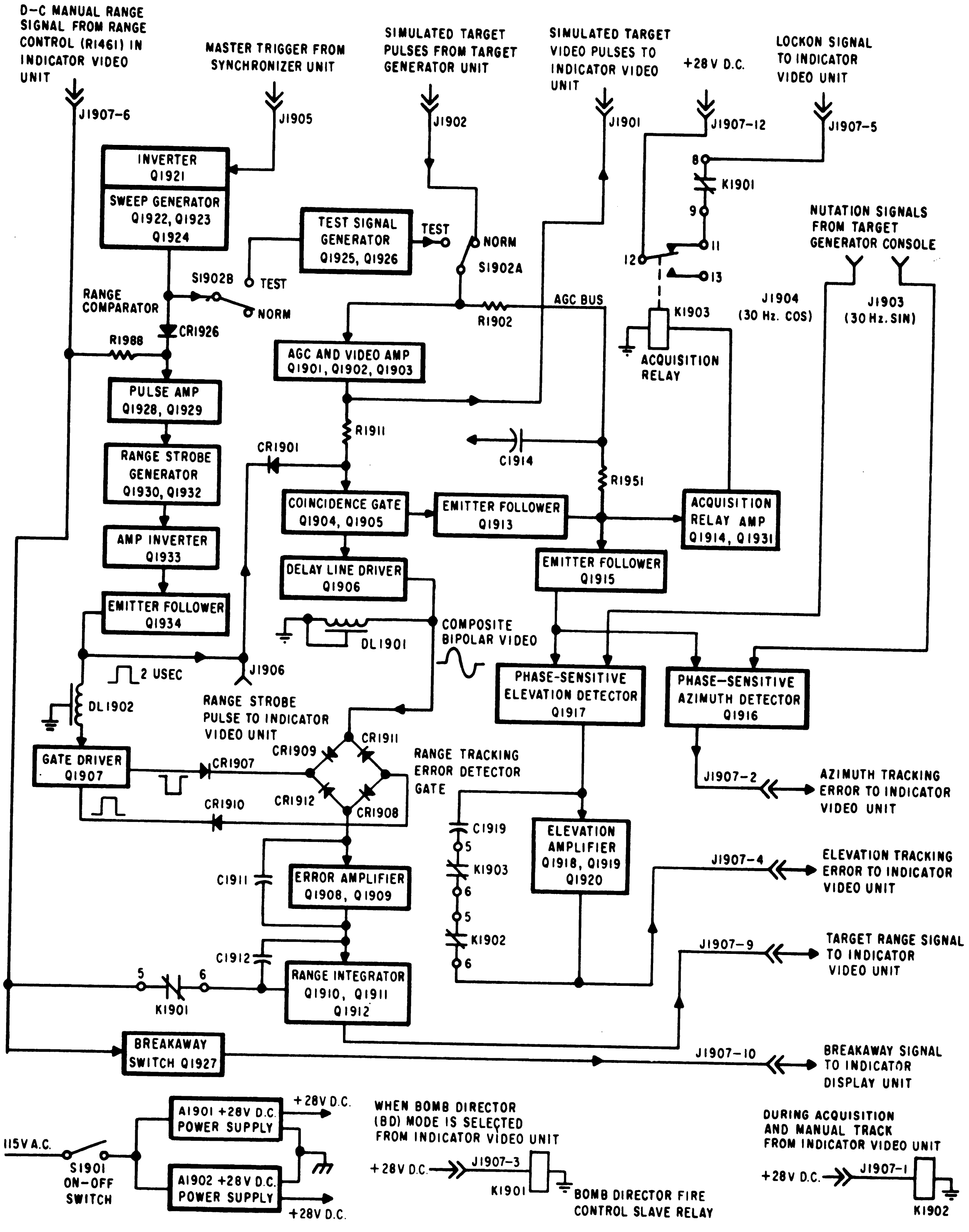
D-C MANUAL RANGE SIGNAL FROM RANGE CONTROL (R1461) IN INDICATOR VIDEO UNIT
J1907-6
MASTER TRIGGER FROM SYNCHRONIZER UNIT
J1905
SIMULATED TARGET PULSES FROM TARGET GENERATOR UNIT
J1902
SIMULATED TARGET VIDEO PULSES TO INDICATOR VIDEO UNIT
J1901
+28V D.C.
J1907-12
LOCKON SIGNAL TO INDICATOR VIDEO UNIT
J1907-5
INVERTER Q1921
SWEEP GENERATOR Q1922, Q1923 Q1924
TEST SIGNAL GENERATOR Q1925, Q1926
TEST
NORM
S1902A
8
K1901
9
NUTATION SIGNALS FROM TARGET GENERATOR CONSOLE
12
11
13
S1902B
TEST
RANGE COMPARATOR
NORM
R1902
AGC BUS
K1903
J1904 (30 Hz. COS)
J1903 (30 Hz. SIN)
CR1926
R1988
AGC AND VIDEO AMP Q1901, Q1902, Q1903
ACQUISITION RELAY
PULSE AMP Q1928, Q1929
R1911
CR1901
C1914
RANGE STROBE GENERATOR Q1930, Q1932
R1951
COINCIDENCE GATE Q1904, Q1905
EMITTER FOLLOWER Q1913
ACQUISITION RELAY AMP Q1914, Q1931
AMP INVERTER Q1933
DELAY LINE DRIVER Q1906
EMITTER FOLLOWER Q1915
EMITTER FOLLOWER Q1934
DL1901
COMPOSITE BIPOLAR VIDEO
2 USEC
J1906
DL1902
RANGE STROBE PULSE TO INDICATOR VIDEO UNIT
PHASE-SENSITIVE ELEVATION DETECTOR Q1917
PHASE-SENSITIVE AZIMUTH DETECTOR Q1916
CR1909
CR1911
GATE DRIVER Q1907
CR1907
RANGE TRACKING ERROR DETECTOR GATE
J1907-2
AZIMUTH TRACKING ERROR TO INDICATOR VIDEO UNIT
CR1910
CR1912
CR1908
C1919
5
ELEVATION AMPLIFIER Q1918, Q1919 Q1920
K1903
6
J1907-4
ELEVATION TRACKING ERROR TO INDICATOR VIDEO UNIT
C1911
ERROR AMPLIFIER Q1908, Q1909
5
K1902
6
J1907-9
TARGET RANGE SIGNAL TO INDICATOR VIDEO UNIT
C1912
5
6
K1901
RANGE INTEGRATOR Q1910, Q1911 Q1912
BREAKAWAY SWITCH Q1927
J1907-10
BREAKAWAY SIGNAL TO INDICATOR DISPLAY UNIT
A1901 +28V D.C. POWER SUPPLY
+28V D.C.
115V A.C.
S1901 ON-OFF SWITCH
A1902 +28V D.C. POWER SUPPLY
+28V D.C.
WHEN BOMB DIRECTOR (BD) MODE IS SELECTED FROM INDICATOR VIDEO UNIT
+28V D.C.
J1907-3
K1901
BOMB DIRECTOR FIRE CONTROL SLAVE RELAY
DURING ACQUISITION AND MANUAL TRACK FROM INDICATOR VIDEO UNIT
+28V D.C.
J1907-1
K1902

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Figure 8-20.—Range tracking unit block diagram.

operates a bootstrap sweep generator. Recall that the output of a bootstrap sweep generator is a sawtooth wave of voltage, which is very linear. The starting point of the sweep sawtooth is in coincidence with the system trigger, and the width of the sweep is dependent upon whether the system is operating in FC or BD mode. This sawtooth is then applied to CR1926, which is a range-comparator diode.

Since CR1926 is a comparator, it must have something with which to compare the sweep sawtooth. The voltage to be compared is the range voltage shown in the illustration as dc manual range signal. This manual input comes from the range potentiometer R1461 in the indicator video unit, and is applied to R1988 through J1907, and then to the comparator CR1926. An output is developed across R1988 when the amplitude of the sweep sawtooth exceeds the dc range voltage. Thus, the comparator output is delayed in time by an amount corresponding to range strobe position (range).

The output of the comparator is then amplified to sharpen the leading edge and is used to trigger the range strobe generator. The range strobe generator is a monostable multivibrator, which generates a 2-μsec pulse each time it is triggered. The 2-μsec pulse is then amplified, inverted, and taken from Q1934, an emitter follower, as a 2-μsec positive range strobe pulse. The range strobe is next applied to delay line DL1902, and then to gate driver Q1907. Note also that the range gate is applied to J1906 (and sent to the indicator video unit) and to the coincidence gate through CR1901.

The target that is to be tracked is an input at J1902 through switch S1902A and into AGC and video amplifier. The amplified video pulses are an output to the indicator, through J1901, and are also an input across R1911 into the coincidence gate. If the range strobe pulse is in coincidence in time with the target video pulse, the coincidence gate will accept the video pulses. The coincidence gate provides a negative output to emitter follower Q1913, and a positive output to delay line driver Q1906.

The output of the emitter follower is filtered across R1951 and C1914 and used as AGC voltage for the video amplifier. The AGC voltage also operates the acquisition relay amplifiers, which deenergize K1903 when the AGC voltage is sufficient to allow tracking. When K1903 is deenergized, 28 volts is coupled across the relay contacts 12 to 11 and is an output at J1907 to the indicator video unit as a lockon signal.

The delay line driver output is a 1-μsec pulse. This pulse is the output of the coincidence circuit, which has been differentiated and amplified. The 1-μsec pulse is applied to the delay line DL1901, which has a 0.5-μsec delay. Remember, any signal applied to this delay line will require 1-μsec to travel down the line and back again, using 0.5-μsec in each direction. This means when the signal returns (1 μsec later) the original signal has passed (in time) and the reflected signal, which is inverted, will cause the waveform to continue (in time) forming the last half of the composite bipolar video waveform as illustrated. The entire bipolar video waveform is 2 μsec in duration.

Next, the bipolar video is applied to the error detector gate, which is formed of diodes CR1907 through CR1912. Note that a pair of 1-μsec gates, from gate driver Q1907, is also applied to the error detector gate at the same time. These gates have been delayed approximately .8-μsec by DL1902 and the transit time of the gate driver. The duration of these gates is 1-μsec; therefore, the error detector gate is open for 1-μsec. If the bipolar video signal is present and is centered in the gates, an equal portion of the video composite signal is gated through the error detector and the output is zero. If the target should move (in range), the gates will appear earlier or later, and the bipolar video will not be centered in the gate. The output of the error detector will now be either positive or negative, respectively.

These error voltages, during automatic track, represent the range changes of the target and indicate an error between the target and the tracking gate. The gates then must be moved in order to track the target. This operation is accomplished by the range voltage change, which is returned to the range comparator from the range integrator across K1901 and R1988. For example, if the range of the target has decreased, range voltage out at the range integrator will decrease; this decrease is felt at the range comparator as the range sweep voltage sawtooth will require less time to overcome the range voltage now at the junction of CR1926 and R1988, triggering the range strobe generator earlier. The range strobe will appear earlier, and the composite video pulse will again be centered in the tracking gate. Range voltage out is also used to operate the breakaway switch Q1927, which produces a signal for the breakaway circuits in the indicator display unit. Finally, the range of the target is an output at J1907-9 and is used in the indicator video unit.

Antenna azimuth and elevation error tracking signals are also detected in the tracking chassis. These voltages are obtained by detecting the amplitude modulation of the target signal and by comparing the phase of this modulation on the input target video pulses with a reference signal. Target video that was applied to the AGC bus is also applied to emitter follower Q1915, which detects the amplitude modulation carried by the input target video pulses. The detected modulation is then applied to the elevation and azimuth phase detectors. The amplitude modulation represents the radial error between the target and the antenna and is phase compared with the reference voltage. The reference voltage is the target generator nutation signal applied to the phase detectors through J1903 and J1904. The output of the phase detectors is a dc voltage whose polarity indicates direction of the error, and whose amplitude represents the amount of error. These outputs are then applied to the appropriate antenna tracking circuits.

The block in the illustration labeled test signal generator simply provides a signal for the tracking unit during maintenance and bench testing. To operate the test generator S1902, the test normal switch is activated.

ANTENNA AND ANTENNA CONTROL

Since an antenna positioning servosystem was described in detail in Chapter 3 of this manual, the antenna is only briefly discussed in this chapter. During the discussion refer to figure 8-21, which is a block diagram of the antenna and antenna control.

The antenna unit consists of control transformer B852, synchronous motor B851, a gear reduction arrangement, and the reflector and feed horn assembly. This group is shown on the right side of the illustration. The synchronous motor provides driving power to rotate the antenna in azimuth when it is energized by the signal from the magnetic amplifier T1802 in the antenna controller. The gear reduction provides the necessary reduction required to drive the antenna at the automatic rate of 6 rpm. The control

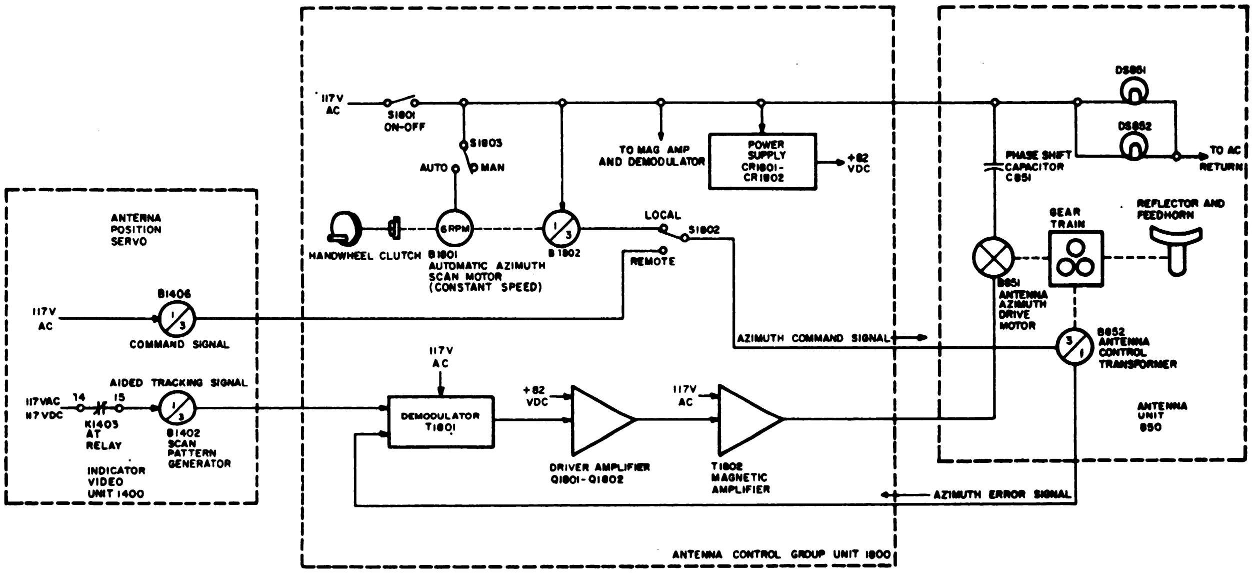

Figure 8-21.—Antenna and antenna control block diagram.

transformer is mechanically connected to the antenna through the gear reduction arrangement at a ratio of one-to-one; thus, it continuously samples antenna azimuth position and feeds this signal back to the demodulator T1801. This signal is an error signal, which is compared with the command input.

The antenna control group (fig. 8-21) consists of synchronous motor B1801 (constant speed scan motor) and synchro generator, demodulator T1801, driver amplifier, magnetic amplifier T1802, a power supply, and necessary controls and switches. These items are shown in the center of figure 8-21. To the left of the control group is a portion of the indicator video unit. Recall that the antenna positioning servo and the scan pattern generator were part of this unit. Inputs to the antenna control group from the antenna position servo are shown as inputs to the demodulator T1801 and local remote switch S1802.

Switch S1802 determines whether the azimuth command signal is taken from the antenna position servo or from the azimuth scan motor. If the local remote switch is in the position shown, and if the on-off switch S1801 is closed, the 117-volt ac reference phase voltage is applied to the rotor winding of synchro generator B1802. This voltage induces, in the stator winding, a voltage whose phase and amplitude depend upon the angular displacement between the rotor and stator windings. The stator of the synchro generator is connected in parallel with the stator winding of synchro transformer B852 in the antenna unit so that the same signal voltage is present in the stator windings of each synchro. Since the rotor winding of B852 is mechanically linked to the antenna drive gearing, its position represents the position of the antenna. The voltage induced in the rotor of B852 represents the difference between the position of the antenna and the command signal generated by B852 and is the error voltage.

This error voltage is applied to demodulator T1801, where it is compared with the reference-phase voltage. An output signal is produced by T1801 whose amplitude and polarity are determined by the relative phase difference between the error voltage and the reference voltage. The output of T1801 is applied to a driver amplifier, operated push-pull, and is then coupled directly to magnetic amplifier T1802. In the magnetic amplifier, the signal is rectified and used as a dc bias voltage to bias the saturable reactor along its hysteresis curve. Effectively, the error voltage from the demodulator is used to vary the inductance of the magnetic amplifier. This controls the amplitude and polarity of the magnetic amplifier output, which is then applied across a sensitivity control and used to drive the antenna azimuth drive motor. Note also that the reference phase voltage is fed to B851; this is applied to the fixed phase winding of the azimuth drive motor. S1803 in the antenna control is used to determine whether the command signal is automatic or manual.

Setting the local remote switch to remote allows the synchro generator in the antenna servo to assume command of antenna rotation. If the system is operating in the automatic search submode of fire control, an additional signal is applied to the demodulator. This signal is called aided tracking signal. Recall that during automatic search in fire control, sector scan is used; therefore, an increase in the driving signal is required to overcome the inertia and velocity effects of the antenna, which occur during sector scan rates in fire control search operation.

ANTENNA STABILIZATION PLATFORM

The purpose of stabilization is to isolate the antenna from motions of the aircraft. The motions that would destroy the effectiveness of an attack on an airborne or surface target are the roll and pitch of the aircraft as the pilot maneuvers into a position to release a missile or drop a bomb. Figure 8-22 illustrates what happens when the motions of the aircraft have not been compensated.

Stabilization in an operating radar is required during search and acquisition operation. After radar lockon, the position of the antenna is slaved to the target tracking circuits and antenna position servo. These circuits continuously move the antenna, and at the same time provide information for steering, which is placed on the indicator as previously described. During search operations, the search pattern is stabilized to prevent loss of the target. In an actual radar, position signals are derived from the gyros, which are normally a part of the stabilization platform. These signals are fed to the antenna servosystem to displace the antenna scan position when the

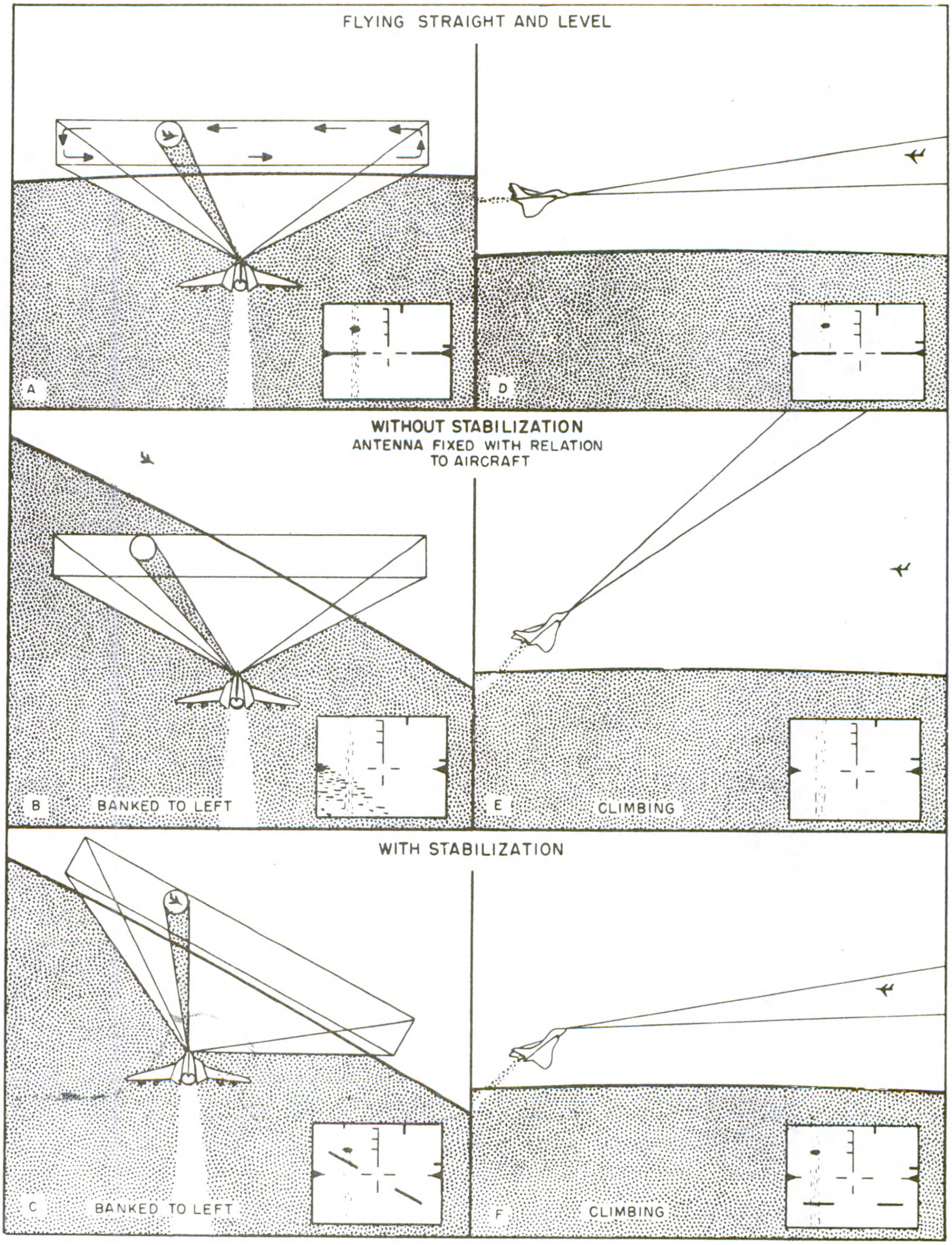

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Figure 8-22.—Effect of antenna stabilization.

aircraft deviates from the straight and level flight attitude. When the aircraft is banked (roll), the antenna is moved (tilted) in the opposite direction the same amount, thereby maintaining the scan parallel to the horizon. Similarly, when the aircraft climbs or dives (pitch), the antenna is raised or lowered (tilted) to maintain the elevation position with respect to the horizon as set by the pilot. Combined roll and pitch maneuvers result in a corresponding displacement of the antenna scan in the opposite direction. Thus, the position of targets on the scope is changed only by a change in relative azimuth-bearing and range. The effect of an aircraft in banking and climbing maneuvers with no stabilization is illustrated in (B) and (E) of figure 8-22. Note loss of the target on the scope. Parts (C) and (F) illustrate the same maneuvers but with stabilization.

Since the antenna scan and the artificial horizon line are positioned by the same signal, displacement of the scan can be visualized by observing the artificial horizon line. For mapping or bombing, the antenna is tilted slightly downward to pick up ground returns and the indicator displays a map of the forward area. After the pilot has positioned the antenna to scan the desired area, stabilization to that position is maintained as before. (See fig. 8-23.)

In the trainer 11D13A, roll and pitch motions are inserted manually. Figure 8-24 illustrates the trainer stabilization platform. When either gimbal is upset, a gear arrangement driven by separate pitch and roll servosystems drives the respective gimbals back to the horizontal. The servosystems, both azimuth and elevation, are identical except for one operation; because of mechanical limitations, the elevation functions (tilt) are incorporated in the pitch-stabilization system, as shown in the upper left corner of the diagram. The inputs shown here are electrical, and will have no effect on the stabilization of the antenna, since to stabilize requires mechanical inputs. The operation of the pitch servo is described in the following paragraphs; roll is not described since the operation is practically identical.

Referring to figure 8-24, note that the pitch error signal is developed at R1006. R1006 is referenced to the roll gimbal by being firmly mounted on the roll gimbal frame. The input is indicated as aircraft pitch, which in an actual stabilization system would be an output from a pick-off of a gyro.

Any movement of the wiper arm of R1006 results in either a positive or negative voltage picked off between −25 and +25 volts dc. This, then, is the error signal, and is an input to the

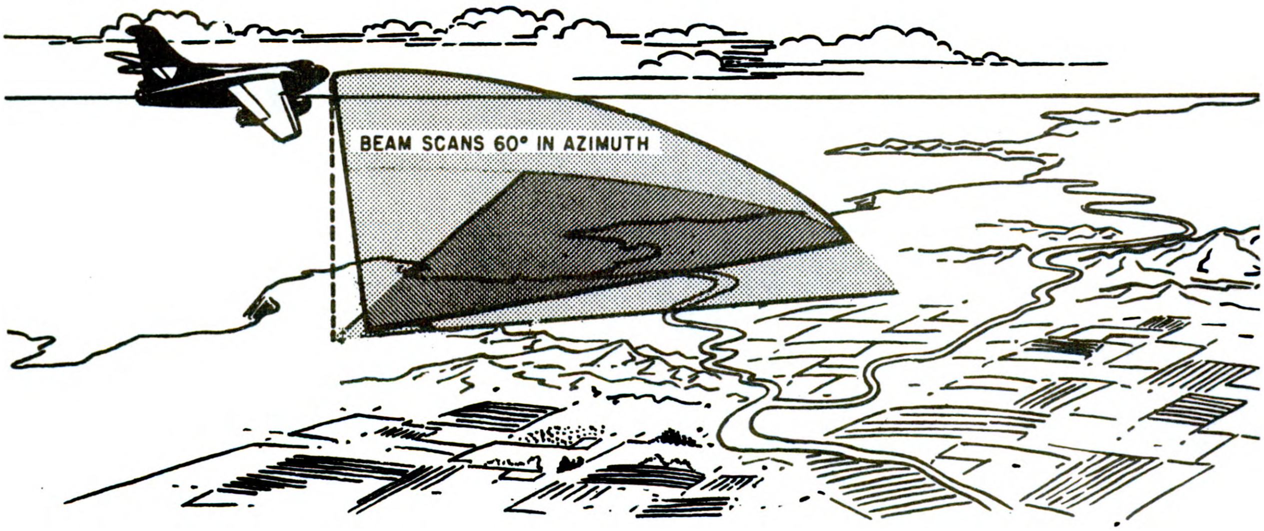

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Figure 8-23.—Antenna scan for mapping and bombing.

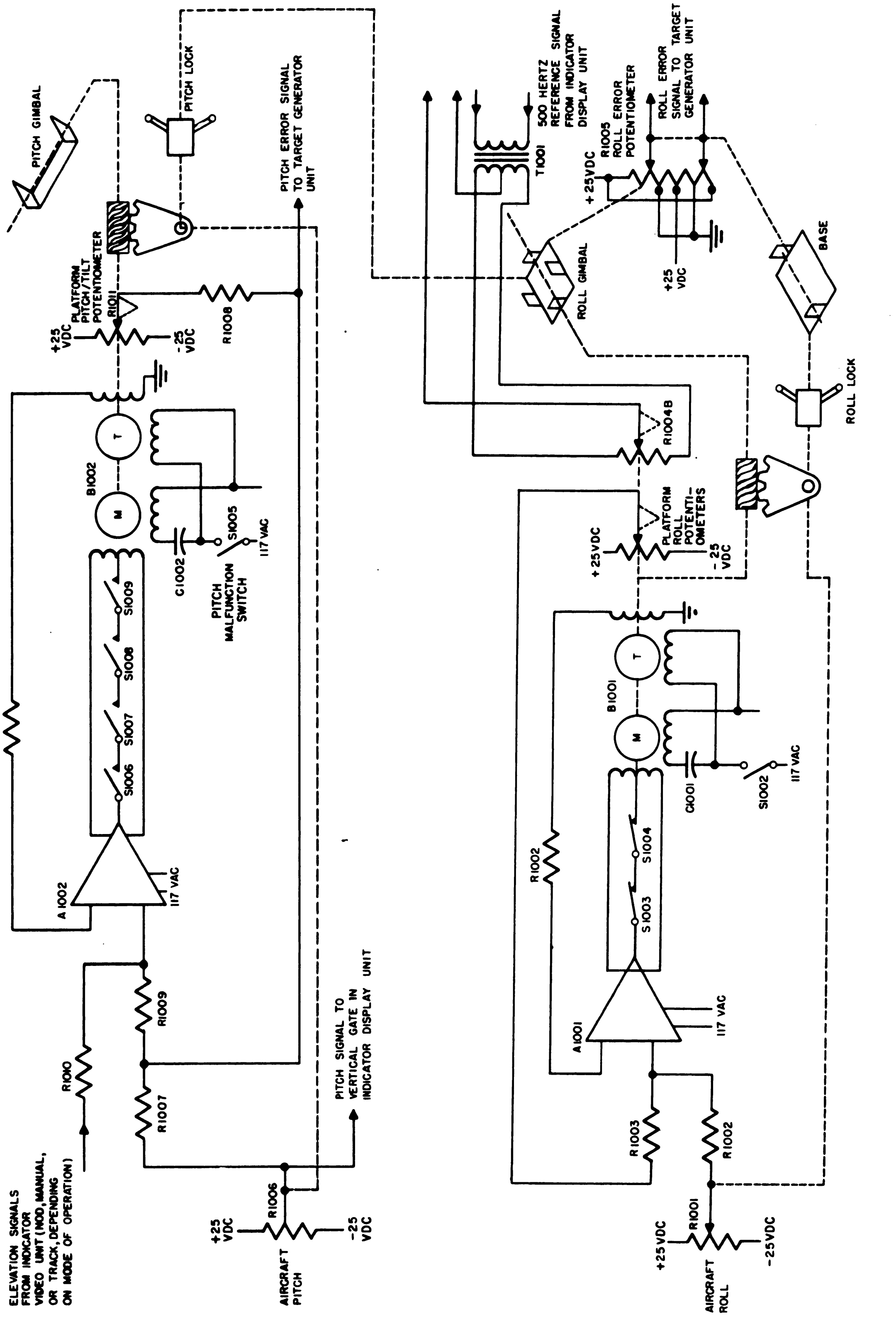
ELEVATION SIGNALS FROM INDICATOR VIDEO UNIT (NOD, MANUAL, OR TRACK, DEPENDING ON MODE OF OPERATION)
R1010
R1007
R1009
A1002
117 VAC
R1013
S1006
S1007
S1008
S1009
B1002
M
T
C1002
PITCH MALFUNCTION SWITCH
S1005
117 VAC
+25 VDC
-25 VDC
R1011
PLATFORM PITCH/TILT POTENTIOMETER
R1008
PITCH GIMBAL
PITCH LOCK
PITCH ERROR SIGNAL TO TARGET GENERATOR UNIT
PITCH SIGNAL TO VERTICAL GATE IN INDICATOR DISPLAY UNIT
AIRCRAFT PITCH
+25 VDC
R1006
-25 VDC
AIRCRAFT ROLL
+25VDC
R1001
-25VDC
R1003
R1002
A1001
117 VAC
R1002
S1003
S1004
C1001
S1002
117 VAC
B1001
M
T
+25VDC
PLATFORM ROLL POTENTI-OMETERS
-25 VDC
R1004B
ROLL LOCK
BASE
ROLL GIMBAL
T1001
500 HERTZ REFERENCE SIGNAL FROM INDICATOR DISPLAY UNIT
+25VDC
R1005 ROLL ERROR POTENTIOMETER
ROLL ERROR SIGNAL TO TARGET GENERATOR UNIT
+25 VDC

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Figure 8-24.—Antenna stabilization platform.

platform servosystem across R1007 and R1009 to the servoamplifier A1002. A second output is taken from between R1007 and R1009, and is the pitch error signal for positioning the target being generated by the target generator. A third signal is the pitch signal to the vertical gate in the indicator display unit.

There are four switches between the amplifier and the drive motor. These are limit switches S1006 through S1009. S1006 and S1007 protect the gimbal mechanism when the extremes are reached, and S1008 and S1009 prevent the operator from injecting a combined error in pitch and tilt of more than 45°. Pitch malfunction switch S1005 is used by the operator to simulate a malfunction in the pitch servosystem. During normal operation, all switches are closed, and motor B1002 drives potentiometer R1011 back to its original position. At the same time, the worm gear is also driven, which operates the sector gear mechanically linked to R1006. This motion returns R1006 and the pitch gimbal to the null position. During the erection period, potentiometer R1011 also produces a feedback to the amplifier, which is in opposition to the error input. During manual track, or nod inputs, feedback is from the generator across R1013 to cancel out the original input when the antenna has reached the desired tilt position. During this time, R1011 feeds back to cancel the input from R1006.

SYSTEM TESTING

In the field of radar, reliance cannot be placed solely on scope interpretation by the technician to judge the range capability and data accuracy of radar systems unless BIT checks are used. It has been found to be so inaccurate that it is completely valueless. Numerous tests in the field strongly emphasize this fact. In one instance, the performance of approximately 100 different radar sets was carefully measured with test equipment of known accuracy. In each case, the radar set under test was considered to be in normal operating condition by the radar personnel involved. The results of these tests revealed that, on the average, the maximum effective range of the radar equipments under test was only one-half the maximum range possible, had the equipment been operating at peak efficiency. In fact, five radar sets were found to be operating at less than 10 percent of their maximum range, which means, in effect, that these radar equipments were protecting only 1 percent of their assigned tactical areas. Since such poor performance, as demonstrated by these tests, may have serious consequences. It can readily be seen that performance testing is of the utmost importance in radar work. An investigation to find the cause of this unsatisfactory situation showed that many technicians are not sufficiently familiar with the techniques and procedures necessary to test microwave radar systems properly.

Radar performance testing involves a series of measurements primarily intended to indicate the ability of the radar to detect targets. The combined results of the tests then indicate the overall radar performance. Two distinct and separate factors are involved in the consideration of radar performance, (1) minimum range performance, and (2) maximum range performance.

MINIMUM RANGE PERFORMANCE

The TR recovery time and the transmitter pulse width are important factors in determining the effective minimum range. If a target has a range of 200 yards, the echo is returned to the radar in about 1-1/4 microseconds after the occurrence of the transmitter pulse. If the receiver is to respond to this echo, the TR switch must recover sufficiently during this short interval to allow passage of energy to the receiver. Since a nearby target returns a strong signal, the recovery need not be complete. The receiver responds to a strong signal even at reduced sensitivity.

Minimum range performance is also influenced by the transmitter pulse width. Long range search radar facilities may use a pulse width of 2 microseconds or greater, which represents a free-space range of over 320 yards. Radars designed for close range work have pulse widths as short as one-quarter microsecond, which represents only a little over 400 yards of free-space range.

MAXIMUM RANGE PERFORMANCE

The factors which determine the maximum range of a radar are rather diverse. However, for the purpose of the following discussion, they may be divided into two general categories. The first category, which is not controllable by the maintenance activity, consists of target reflection and propagation factors. The second category is made up of performance factors, which are controllable to some degree by the maintenance activity.

Target reflection is a direct function of target size. Four principle factors which enter into the determination of the amount of energy reflected by a radar target are as follows:

1. The material of which the target is constructed.
2. The surface area presented to the radar.
3. The configuration of the surface presented to the radar.
4. The operating frequency of the radar.

In general, it can be said that the amount of energy reflected from a target is a very complex consideration, and that the reflected signal energy cannot be predicted with any degree of accuracy. Therefore, when information on the reflected-signal strength is required, it is best found by direct measurement.

Atmospheric conditions play a very important part in radar performance. Some of the more common factors are as follows:

1. Dust formation.
2. Temperature inversion and atmospheric refraction.
3. Rain echoes and scattering.
4. Atmospheric absorption.

Atmospheric conditions relating to radar operation are covered in Chapter 4 of *Avionics Technician 3 & 2* Part 1, NAVEDTRA 10319.

Maximum range performance also depends upon the condition of the radar. Radar condition is the only factor which may be controlled to some degree by maintenance, and therefore is the most important. Radar equipment performance is dependent upon such items as transmitter power, frequency, spectrum, receiver bandwidth and sensitivity (mds), TR recovery time, and AFC operation. These items are all covered in Chapter 13 of this manual.

Testing of complex weapon systems demands strict adherence to prearranged procedures as set forth in the appropriate maintenance equipment manuals. Indiscriminate alignment adjustments or testing must not be attempted. The technician MUST refer to and follow the approved procedures provided.

SYSTEM TROUBLE ANALYSIS

Technicians are generally given technical training in the equipment they are to maintain, but to be proficient troubleshooters, they must supplement this training in two ways: (1) they must learn to identify those faults in a radar set which can be located by simple observation; and (2) when faults cannot be located by these means, they must divide the radar set into operating systems and subsystems so that the faulty component can be quickly isolated.

With a few exceptions, all troubles which cannot be identified by a simple observation can be located by a logical process, which breaks the radar set into major independent operating systems, and these systems, in turn, into subsystems. In so dividing the radar set, technicians can disregard the systems and subsystems which are operating properly and concentrate their troubleshooting on the elements which exhibit abnormal functioning, so they get directly at the source of trouble with maximum efficiency.

For this method of troubleshooting to be most effective, the technician must bear in mind several important considerations in the selection of systems and subsystems. The foremost of these considerations include the following:

1. The breakdown of a system into subsystems should be such that the tests required to determine the faulty subsystem are quick, direct, and easy to make.
2. The number of subsystems within any system must be kept low.
3. All the subsystems within a system should be selected as having approximately an equal chance of failure.
4. Systems and subsystems not related to the trouble being traced should not be included at the same level of importance as those regarded most probably at fault. As the technician develops a growing technique of logical breakdown, the ability to isolate and identify troubles quickly and correctly will grow in proportion.

SUMMARY

This chapter acquainted you with a complete radar system. A radar system which is operationally representative of those found in modern weapon system installations. The following is a summary of the important points in the chapter.

BASIC RADAR—The basic elements of a radar are a transmitter, receiver, antenna, and synchronizer. Additional elements permit tracking and antenna stabilization.

MODES OF OPERATION—The trainer presented in this chapter is capable of operating in three basic modes. The three modes available are search, fire control, and bomb director. The submodes are automatic search, manual search, acquisition, automatic track, and breakaway.

SYSTEM CONTROLS—The controls of the trainer can be grouped into five major categories according to their function. The five major control functions are:

1. Power switch.
2. Mode switch.
3. Receiver gain control.
4. Antenna azimuth and elevation control.
5. Range control.

INDICATOR DISPLAYS—The display indicators (PPI and B-scope) display information resulting from operating in the basic modes and submodes of operation. These are as follows:

1. Basic search.
2. Fire control (automatic search).
3. Fire control (manual search).
4. Fire control (lockon).
5. Fire control (automatic track).
6. Fire control (breakaway).
7. Bomb director mode.

RADAR SYSTEM UNITS—The major units of a typical radar system are as follows:

1. Synchronizer.
2. Transmitter.
3. Receiver.
4. Indicator.
5. Indicator video unit.
6. Range tracking unit.
7. Antenna and antenna control.
8. Antenna stabilization.

The synchronizer develops all timing signals required for proper operation of the radar.

The transmitter generates RF pulses which are transmitted to the RF system.

The receiver accepts returned target echoes from the antenna and duplexer system and transforms them into video signals.

The indicator unit displays (PPI and B-scope) all the information needed by a pilot to make a successful intercept attack on an airborne target, or a bombing attack on a surface target.

The indicator video unit is the systems interconnection and control center. It generates antenna positioning signals, the radar scan pattern, and PPI sweep and deflection signals. It also processes and amplifies all video signals for both indicator displays. Most signals of the system are interconnected through the video unit.

The range tracking unit allows the radar to track a target in range. When the input video is provided by the target generator, it develops antenna azimuth and elevation signals, giving the radar the ability to track in angle as well as range.

The antenna radiates RF energy into space and receives returned target echoes. The antenna control is primarily an antenna positioning servosystem.

The antenna stabilization unit isolates (separates) the antenna from motions of the aircraft.

CHAPTER 9

PRINCIPLES OF NAVIGATION

Previously, we have discussed handtools and materials, servosystems, data sensing elements, weapon control fundamentals, the bombing problem, radar circuits, and weapons control radar. In this chapter, you will be presented with a discussion of the principles of navigation.

The introduction of aircraft with inertial navigation systems creates a whole new set of problems in operation, maintenance, and deckhandling. In this chapter, the fundamentals of inertial navigation systems and the Doppler radar systems used with them are presented. The effects of component and initialization errors on navigation are also discussed. Initialization is the process of bringing the inertial system to a set of initial conditions from which it can proceed with the navigation process. A description of system initialization on the ground and on board aircraft carriers is given. Since it is the most difficult to deal with, carrier environment will be emphasized.

NAVIGATION

There are two methods of navigation. One is position fixing by measuring position relative to some known object. Celestial navigation is an example of navigation by periodic position fixes. The other method is dead reckoning which measures speed and heading and, using these measurements, computes position change from an initial position fix. The most common example of this form of navigation is the ship navigator's position plot. One of the oldest automatic navigation systems is the dead reckoning analyzer, which takes its speed from the ship's log and its heading from the ship's gyrocompass to compute latitude and longitude. A more accurate automatic dead reckoning device is the Doppler radar navigator.

Navigation systems which require a continuous record of position normally use both methods; that is, since it is not always convenient to establish position continuously by a direct fix, they dead reckon between position fixes. However, the error in dead reckoning, as a percentage of the distance traveled, commonly reaches 2 to 5 percent. Thus, as the distance traveled between fixes increases, as in the case of high speed aircraft, the accuracy of dead reckoning must be increased if a small absolute position error is to be maintained.

DEAD RECKONING

The concept of dead reckoning is well known, but the source of error and methods of increasing the accuracy of dead reckoning are not. To navigate by dead reckoning, the vehicle's speed is resolved, using the vehicle's heading into north and east velocities. The time integral of these velocities give the distance traveled or the change in latitude and longitude from the last position fix.

The two major causes of error in position computed by dead reckoning are errors in the measurements of heading and speed. A heading error of 1° introduces an error of 1.75 percent of distance traveled. A speed error of 1 percent introduces an error of 1 percent of distance traveled. Assuming these errors to be uncorrelated, the total system error becomes $\sqrt{1.75^2 + 1^2}$, or about 2 percent of distance traveled. Increasing the accuracy of the speed and heading measurements also increases the system accuracy; however, the errors cited above approach the limits of precision of present Doppler navigation equipment.

FUNDAMENTALS OF INTEGRATION

Since the process of integration is so frequently used in navigation systems, a simplified explanation of integration is given here.

NOTE: Integration is also discussed in *Mathematics*, Volume 2, NAVEDTRA 10071 (Series).

In inertial navigation, distance traveled is calculated from measured acceleration by first integrating acceleration with respect to time to find velocity, and then integrating velocity with respect to time to find distance traveled. In calculus, distance, velocity, and acceleration are related as follows:

$$x = \int V\,dt = \int\int a\,dt\,dt$$

This formula indicates that distance (x) is equal to the integral of velocity (V) with respect to time (t) and is also equal to the double integral of acceleration (a) with respect to time (t). The three graphs (figure 9-1) illustrate the relationships with acceleration, velocity, and distance.

In order to illustrate these relationships clearly, constant values of acceleration are chosen for each of the first four intervals (time 0 to time 4). Integrating the constant acceleration for time 0 to time 1 gives a velocity (V) which increases linearly. Velocity at the end of the first interval is actually computed by measuring the area under the acceleration curve (time 0 to time 1).

Recall that the fundamental formula for velocity is V = at. The process of integration actually subdivides each interval shown in figure 9-1 into an infinite number of tiny intervals. Integration is, then, the process of adding, or summing, an infinite number of incremental areas under a curve to obtain the total area. The velocity curve, therefore, is a plot of subtotals of the incremental areas under the acceleration curve.

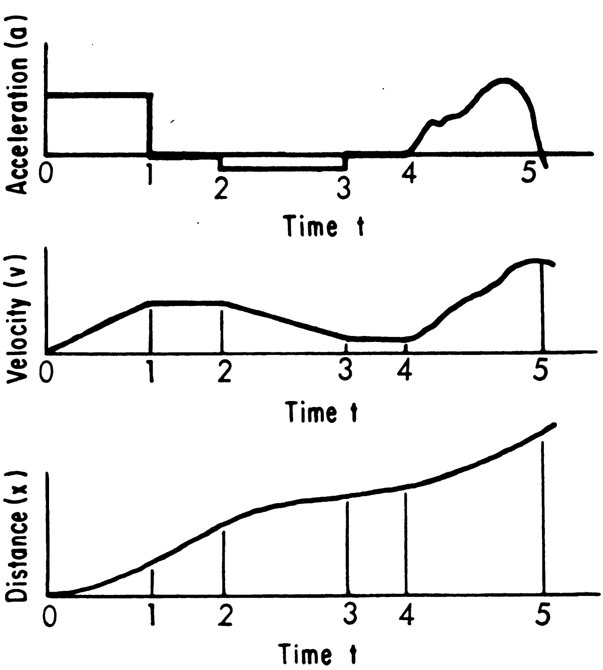

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Figure 9-1.—Integration of acceleration to obtain velocity and distance.

In the second period, the acceleration is zero, and the velocity remains constant. In the third period, there is a constant negative acceleration which reduces the velocity subtotals at a constant rate. In the fourth period, there is no acceleration and no change in velocity. In the fifth period, a random acceleration and its approximate integral, the velocity, are shown.

The distance curve is actually a plot of subtotals of the incremental areas under the velocity curve. A practical example, the ball and disc integrator, is shown in figure 9-2. It is rarely used in inertial navigators, but a very similar device is commonly used in analog computers. The ball (B) is mounted on a splined shaft which is free to turn in bearings. The input to the integrator is the distance "a" (acceleration in this example); that is, the distance between the ball and the center of the disc. The disc rotates at a constant angular rate and its angular position (θ)

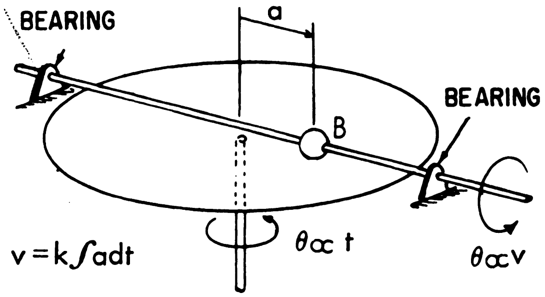

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Figure 9-2.—The ball and disc integrator.

is directly proportional to, or varies directly as time (t), (that is, as shown in figure 9-2, $\theta \propto t$). Rotation of the splined shaft is the output of the integrator, and its angular position θ is directly proportional to velocity (V) in this example. If "a" is zero (the ball is at the center of the disc), the constant disc rotation will not cause the output shaft to rotate, indicating that present velocity is constant. If the ball is displaced from the center of the disc a distance "a," disc rotation causes the splined shaft to rotate, indicating that velocity is increasing. Moving the ball to the left of center of the disc simulates negative acceleration and causes the splined shaft to rotate in the opposite direction, reducing the indicated velocity.

Another example of integration is a simple motor driving a counter. If a voltage proportional to velocity is present, it could be used to drive a motor so that the speed of the motor would be proportional to velocity; and the number of revolutions or the counter reading would indicate distance traveled. Thus, velocity would be integrated to find distance.

INERTIAL NAVIGATION

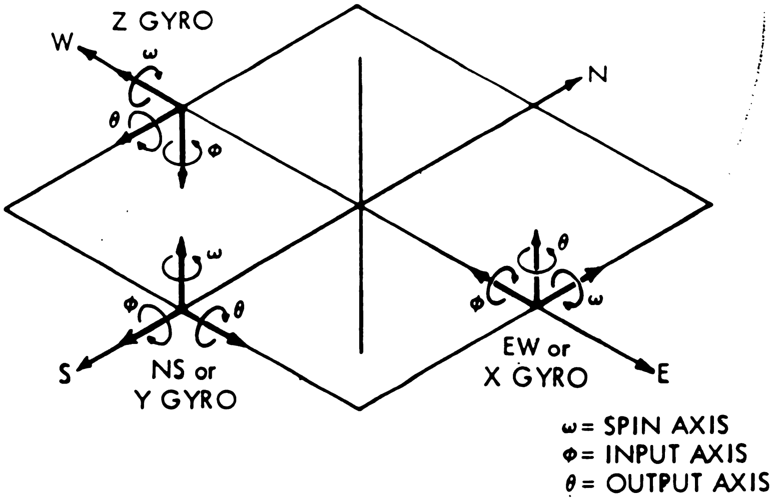
An inertial navigation system is a dead reckoning system with very good accuracy. Instead of measuring speed directly, the system derives it from measurements of the vehicle's accelerations. Two accelerometers are used; one accelerometer is pointed north and the other is pointed east. The first integral with respect to time of these accelerations gives the north and east changes in velocity, and the second integral with respect to time gives the north and east position changes. Of course, the vehicle's initial velocity and initial position must be inserted for accurate navigation.

The accelerometer can be made to measure acceleration very accurately. It cannot, however, distinguish between accelerations of the vehicle and the effect of gravity. This difficulty can be eliminated by keeping the sensitive axis of the accelerometer perpendicular to the gravity vector at all times. To accomplish this, the accelerometers are mounted on a three-axis, gyrostabilized platform.

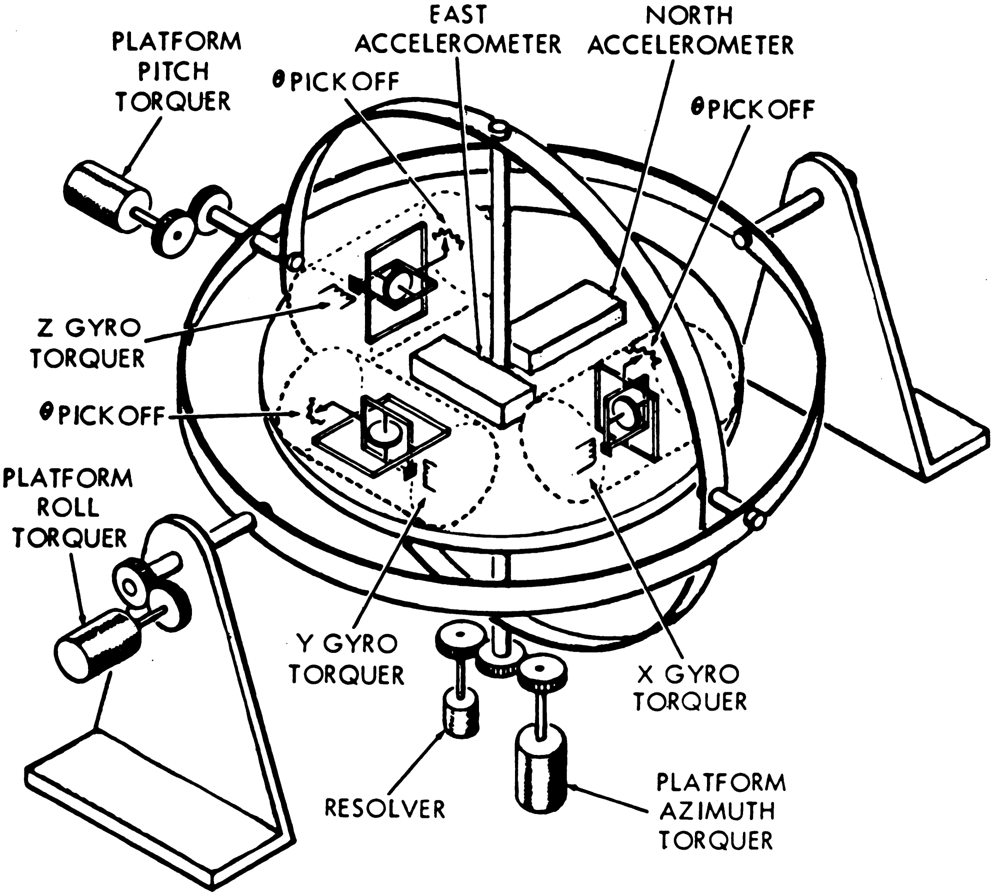
The platform (fig. 9-3) is attached to the vehicle through a gimbal system which permits it to take any orientation with respect to the vehicle. Three gyros are mounted on the platform with their input or sensitive axes in three mutually perpendicular directions. The gyros have the property of sensing angular rates about their input axes. A sensed rate causes the gyro to precess around its output axis, providing an electrical output from the gyro which is amplified and used to drive a platform control torquer to null out the sensed rate. Thus, if the vehicle rotates about any of its three axes, the platform tends to rotate; and the rotation rate is sensed by the gyros. The resulting gyro output causes the platform to be driven in the opposite direction, thus keeping the platform space stabilized while the vehicle rotates around it. Mounting the accelerometers on this platform preserves their orientation independent of the vehicle's rotation. The gyros shown in figure 9-3 are the single-degree-of-freedom type.

Since the integral of angular rate with respect to time is an angle, the platform is commonly described as an integrator. The angle through which the platform moves relative to the vehicle is equal to the negative integral of the vehicle's angular rate.

All is not yet solved. There is one rotation of the vehicle that should be taken into account in orienting the accelerometers. This rotation arises



PLATFORM GYRO-VECTOR ORIENTATION



PHYSICAL ORIENTATION

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Figure 9-3.—Platform control components and gyro vector orientation.

from motion over the earth. Refer to figure 9-4. The vehicle moves from point A to point B. In doing so, it rotates through an angle θ so that it remains level, or perpendicular to gravity. If the platform does not rotate, it will take the position shown at B, and the accelerometers will sense gravity. It is now apparent that the platform must be more than space stabilized. It must be stabilized with relation to the earth, and it will take more than just the output of the gyros controlling the platform torquers to do this.

Since the platform integrates the input rates, an artificial input equal to the negative of the vehicle's angular rate would keep it level. The vehicle's true angular rate ωT (in radians per hour), while the vehicle is traveling over the earth is V_T/R, where V_T is its true linear velocity, and R is the radius of the earth. This artificial signal would be applied to the gyro torquer, which will cause the gyro to move a few degrees around its output θ axis and produce a signal from its θ pickoff even through the input ϕ axis senses no angular rate. By torquing the gyro with $-V_c/R$, where V_c is the computed value of V_T, the gyro θ pickoff output will cause the platform to rotate through an angle relative to the horizontal equal to the integral of $(V_T - V_c)/R$ (which actually would be an error angle). If V_c equals V_T, there will be no error due to the vehicle's rotation while it is traveling over the earth, and the platform will stay horizontal at all times. Since the computed input results from Schuler tuning, the basic principles of Schuler tuning are described below and should be thoroughly understood before proceeding.

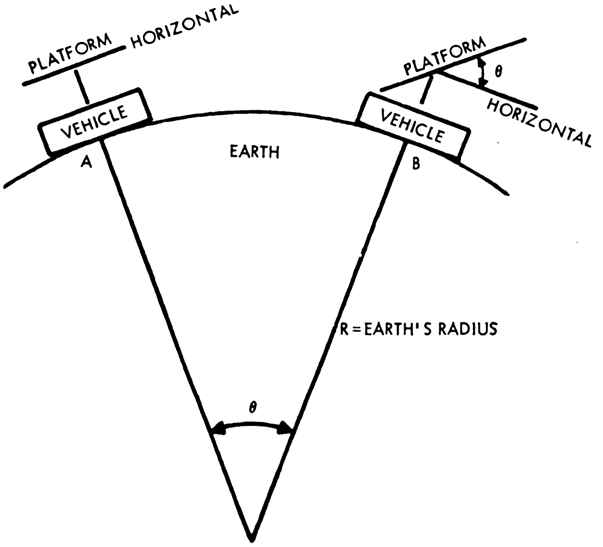

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Figure 9-4.—Vehicle motion in relation to a space stabilized platform.

Accelerometers and Accelerations

Two types of forces that can cause a body to move are acceleration forces and field forces. It is important for you to note that an accelerometer cannot distinguish between these two forces. Newton's second law of motion describes acceleration force thus: If a body is acted upon by a force, the product of the acceleration "a" and the mass "m" of the body is proportional to the force f; $f = ma$. The most common field force is gravity. This force is represented by the formula $f = mg$. The term "g" represents gravitational acceleration, 32.17 ft per sec per sec—the acceleration with which a body falls freely toward the earth's surface, neglecting air friction.

You should understand that the accelerometer will provide no output while it is moving at a constant velocity and its sensitive axis is perfectly horizontal. But if the sensitive axis should become misaligned, gravitational acceleration will result in a force which displaces the mass and causes the accelerometer to give an erroneous indication of the vehicle's acceleration.

Schuler Tuning

Schuler tuning is used in most inertial navigation systems. It maintains the stable platform in an orientation perpendicular to the earth's gravity. It also reduces the long-term errors, described later, resulting from certain imperfections in the instruments.

To understand why Schuler tuning was developed and how it operates, consider first some of the problems involved in maintaining a stable platform perpendicular to the earth's gravity. For simplicity, consider the earth to be spherical but nonrotating. A stable platform bearing an accelerometer is shown with respect to the earth in figure 9-5. If the platform is stationary but tilted, as shown in figure 9-5(A), gravitational acceleration will cause the mass in the accelerometer to move to the left and produce an output ($g \sin \theta$) simulating acceleration to the right. The platform can be leveled automatically if the accelerometer output drives the motor (M) (figure 9-5(B)), which rotates the platform through a gear train. The motor turns until the output from the accelerometer is zero when the platform angle θ is also zero.

Now assume that the platform is uniformly accelerated to the right. The mass in the accelerometer will again move to the left; and the output of the accelerometer, after amplification, will drive the platform away from the true level position to a new position where there is zero motor voltage. The action of the accelerometer is exactly the same as that of a pendulum; if accelerated along the earth's surface, they both give an erroneous indication of the vertical.

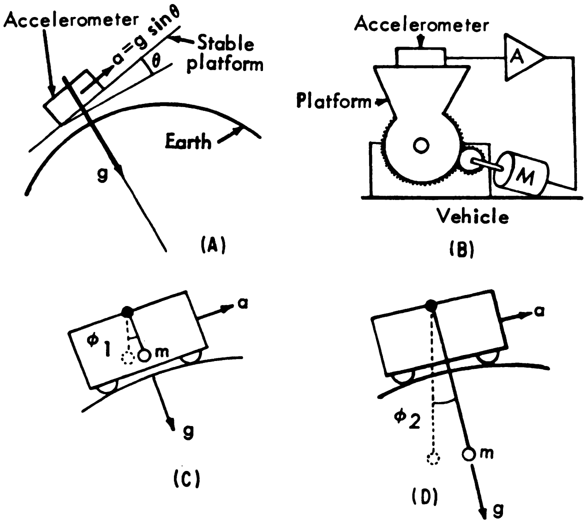

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Figure 9-5.—Basic ideas of Schuler tuning.

Professor Schuler of the University of Gottingen solved this problem, in principle, in the nineteenth century. He considered the case of a pendulum mounted on a moving body, as shown in figure 9-5(C). The vehicle has a pendulum of mass "m" hanging from a pivot. When the vehicle is accelerated, the pendulum lags by an angle ϕ, as shown. In figure 9-5(D), a longer pendulum is used. For any given acceleration, the angle of lag ϕ_2 is less than ϕ_1 in figure 9-5(C). If the pendulum is made longer and longer, the angle of lag becomes less and less. If the pendulum could have its bob at the center of the earth, the angle of lag would be zero and the bob would not move.

Such a pendulum would have to have an effective length equal to the radius of the earth, approximately 4,000 miles, and a period of 84.4 minutes.

The formula for the period of a pendulum is

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where

T = period in seconds
l = length in feet
g = 32.17 ft per sec per sec.

A pendulum with a period of 84.4 minutes can be simulated with electromechanical elements. Taking the output of the accelerometer and

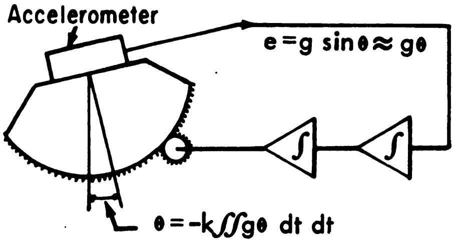

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Figure 9-6.—A Schuler-tuned platform.

integrating it twice before it actually controls the platform provides, essentially, a Schuler-tuned platform. This is shown in figure 9-6. To prove that this loop has an 84.4-minute period and is therefore Schuler tuned, tilt the platform very slightly and observe the following events:

An accelerometer mounted on a platform yields a signal proportional to the tilt angle of the platform (assuming that there is no linear motion of the platform). The output of the accelerometer is

$$e = g \sin \theta$$

For very small angles, the sine of the angle is very nearly equal to the angle in radians; therefore,

$$e = g\theta$$

The angle θ through which the platform moves to correct the tilt is proportional to the double integral of the accelerometer's output,

$$\theta = -k \int\int g\theta \, dt \, dt$$

where

$$k = \text{constant}$$

Differentiating both sides of this equation twice yields the differential equation

$$\frac{d^2\theta}{dt^2} + kg\,\theta = 0$$

A solution to the differential equation is

$$\theta = A \sin (\sqrt{kgt}\,)$$

where

$$A = \text{constant}$$

Since a sine function is involved, the platform is evidently going to oscillate because it was disturbed—this oscillation is very slow. To find the frequency or period of the sine function let

$$\sqrt{kg} = \omega$$

and the following are known relationships

$$\omega = 2\pi F = \frac{2\pi}{T}$$

Therefore

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{kg}}$$

or

$$T = 2\pi\sqrt{\frac{1}{kg}}$$

Now, if we let $k = 1/R$, where $R = 4{,}000$ miles (the radius of the earth), the period T will be equal to 84.4 minutes.

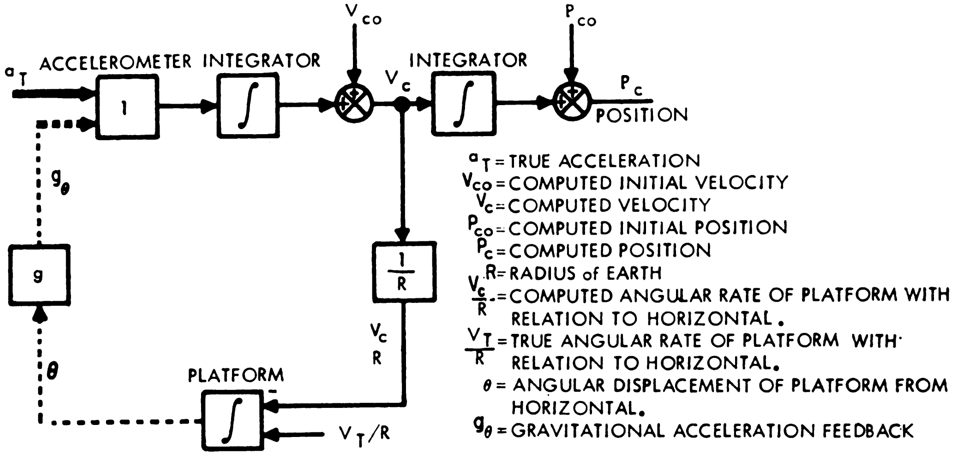
The platform will actually be moved very slowly in a direction to correct the slight erroneous tilt, but it will overshoot and move back. The Schuler loop, therefore, is oscillatory. Once disturbed, the platform continues to oscillate about the vertical like an undamped pendulum. The associated oscillations are called Schuler oscillations. However, proper initialization and accurate components keep these oscillations very small. In fact, some of the inaccuracies which would normally result in large errors after a long period of time are averaged out by the oscillations and result in very little long-term error.

Unlike the usual pendulum system, the Schuler-tuned system is not disturbed by the vehicle's accelerations. Recall that the second integral of acceleration is distance traveled; therefore, as shown in figure 9-6, the amount the platform rotates, θ, as the vehicle moves over the earth is directly proportional to the distance traveled. Consequently, the platform rotates just enough to remain perpendicular to the earth's gravity as the vehicle moves over the earth. In other words, it acts as if it were a pendulum with its bob at the center of the earth.

Schuler Loop

Figure 9-7 contains both a functional and a mathematical diagram of a Schuler loop. For simplicity, only the north loop is shown. Two such loops, one for north and the other for east, are required for an inertial system. The accelerometer in the north loop senses north-south accelerations; however, the gyro in the north loop senses east-west angular rates—the vehicle's angular movements around the east-west axis. (See figure 9-3.)

By convention, the accelerometers and gyros are named according to the direction of their


a_T
ACCELEROMETER
1
INTEGRATOR
V_{co}
V_c
INTEGRATOR
P_{co}
P_c
POSITION
g_θ
g
$\frac{1}{R}$
$\frac{V_c}{R}$
θ
PLATFORM
V_T/R
a_T = TRUE ACCELERATION
V_{co} = COMPUTED INITIAL VELOCITY
V_c = COMPUTED VELOCITY
P_{co} = COMPUTED INITIAL POSITION
P_c = COMPUTED POSITION
R = RADIUS of EARTH
$\frac{V_c}{R}$ = COMPUTED ANGULAR RATE OF PLATFORM WITH RELATION TO HORIZONTAL.
$\frac{V_T}{R}$ = TRUE ANGULAR RATE OF PLATFORM WITH RELATION TO HORIZONTAL.
θ = ANGULAR DISPLACEMENT OF PLATFORM FROM HORIZONTAL.
g_θ = GRAVITATIONAL ACCELERATION FEEDBACK

MATHEMATICAL DIAGRAM

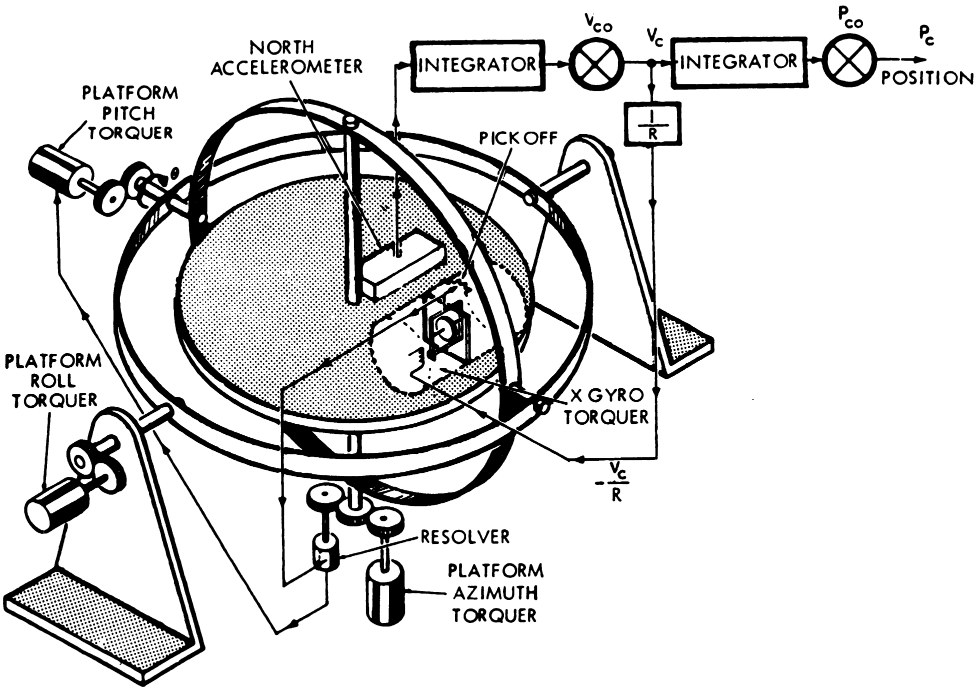


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Figure 9-7.—The north Schuler loop, functional diagram.

input axes; and the inertial or Schuler loop takes the name of its accelerometer. The north loop contains the north accelerometer and X (east) gyro, while the east loop contains the east accelerometer and Y (north) gyro.

Refer to figure 9-7. True acceleration is a_T due to the vehicle's acceleration. An acceleration, $g\theta$, called gravity feedback, is also sensed by the accelerometer when the platform is not perfectly level. It is actually gravitational acceleration "g" (32.17 ft per sec per sec) times the very small tilt angle θ (probably in milliradians).

It has previously been stated, that the platform could be maintained level by torquing it with a signal proportional to $-V_c/R$. Figure 9-7 shows how this is done. The integrated accelerometer output, V_c, is multiplied by l/R to obtain a signal proportional to $-V_c/R$. This signal torques the X (east) gyro to cause it to precess and provide a θ pickoff output through the azimuth resolver to the platform pitch torquer. This, in turn, causes the platform to be torqued through an angle proportional to the distance traveled. In other words, the platform actually integrates the computed angular rate $-V_c/R$ to produce an angle.

V_{co} and P_{co} are both inputs to the system, but only V_{co} has any effect on the Schuler loop. For this explanation, V_{co} is assumed to be zero. Another input (not shown in figure 9-7), that is sensed by the gyro input ϕ axis, is caused by normal flight and combat maneuvers; that is, the angular rate of such maneuvers is sensed by the gyro, causing it to precess and to provide an output through the azimuth resolver to the pitch torquer. The platform torquer responds to these signals, keeping the platform level.

The gyro input ϕ axis also senses V_T/R, which is the vehicle's true angular rate due to the vehicle remaining horizontal as it moves over the earth. V_c/R must be equal to V_T/R; if it is not, the platform will not remain level. The sources and effects of such errors are described later.

Correction Terms

This explanation of inertial navigation has glossed over several important correction terms by assuming a spherical, nonrotating earth. A basic understanding of system operation can be attained without considering these terms. Nevertheless, they are essential for system accuracy and are briefly described.

CORRECTION FOR ALTITUDE AND EARTH's RADIUS.—It has been stated that the stable platform is kept level by rotating the platform at the rate V_c/R. This would be acceptable if the earth were a sphere and the vehicle stayed at the surface of the earth. Since neither of these conditions is met completely, the value of R must be modified to allow for the ellipticity of the earth and for the vehicle's altitude. The new rate of platform rotation required to compensate for these deviations is V_c/R_i, where R_i is the correct instantaneous earth radius. In other words, the l/R term in figure 9-7 is computed continuously as the vehicle's altitude and latitude change. The instantaneous value l/R_i can be expressed by the series formula:

$$\frac{l}{R_i} = \frac{l}{R_p}\left[1 - \frac{e \cos L_i}{R_p} \cdot \frac{h}{R_p}\right]$$

where R_p is the earth's radius at the pole, e is the correction for the ellipticity of the earth, L_i is the instantaneous latitude, and h is the vehicle's altitude.

CORIOLIS CORRECTION.—Accelerometers actually measure acceleration with respect to inertial space. Up to this point, a nonrotating earth has been assumed; therefore, acceleration due to the earth's rotation has been ignored. The difference between the accelerations measured in a vehicle moving over a nonrotating earth and the accelerations measured in the same vehicle moving over a rotating earth is called Coriolis acceleration. Coriolis acceleration occurs because a straight path with respect to the earth becomes a curved path in space when the earth rotates. A curved path can be achieved only by an acceleration force acting at right angles to the flight path, and the accelerometer detects this acceleration. Since the magnitude is a function of the vehicle's instantaneous latitude and the earth's rotation, it is continuously computed and subtracted from the accelerometer output.

CORRECTION FOR EARTH'S ROTATION.—Another correction due to the earth's rotation is required. Since the platform gyros sense rates about the three input axes, they will sense the earth's rotation. The earth's rotation is constant; thus, the compensation rate about each axis is a function of the vehicle's position. A correction rate for each axis is continuously computed and added to V_c/R_i. The resultant signal torques the appropriate gyros to maintain the platform level as the vehicle moves over the rotating earth.

ERRORS IN NAVIGATION

For completeness, more mathematics will be used in the description of system errors; however, system errors can be understood without a thorough knowledge of the mathematics used. The sources of the errors will be described first, and then the major system error due to each source will be considered.

Sources of Errors

Errors in the initial conditions affect the accuracy of the system. There are four initial conditions that must be set before the system can navigate accurately. Two are initial conditions for computation—the initial position, P_{co}, and the initial velocity, V_{co}. Their associated errors are initial position error, $(E)P_{co}$, and initial velocity error, $(E)V_{co}$. The other two are platform initial conditions. Since the platform must be perfectly level, there is probable initial tilt error, θ_o, in each axis; and since the platform must have one axis pointed exactly north and the other east, there is a probable initial alignment error Ψ_o to north.

There are two major component errors—accelerometer bias, Δ_a, and gyro drift rate, $\dot{m}$. They are caused by mechanical imperfections of the components. Accelerometer bias is an erroneous output from the accelerometer when the platform is perfectly level and the vehicle is not accelerating. Gyro drift is an output from the gyro θ pickoff which was not caused by the rotation of the earth or by any movement of the vehicle over the earth's surface. Gyro drift is the more important of the two.

Effect of Errors

The error in the computed velocity, $(E)V_c$, can be computed for each of the errors mentioned above. The equations which give the $(E)V_c$ for each error individually are included and are plotted in figure 9-8. They were derived by using differential equations, and their derivation is considerably beyond the scope of this course. Error in computed velocity, $(E)V_c$, due to an error in initial velocity, $(E)V_{co}$, is

$$(E)V_c = (E)V_{co}\cos\omega_s t$$

where

$$\omega_s = \sqrt{\frac{g}{R}}$$

Error in computed velocity due to gyro drift rate $\dot{m}$ is

$$(E)V_c = \dot{m}\ R\ (l - \cos\omega_s t)$$

Error in computed velocity due to initial platform tilt error θ_o is

$$(E)V_c = \theta_o R\omega_s \sin\omega_{st}$$

Error in computed velocity due to accelerometer bias Δ_a is

$$(E)V_c = (\Delta_a/\omega_s)\sin\omega_s t$$

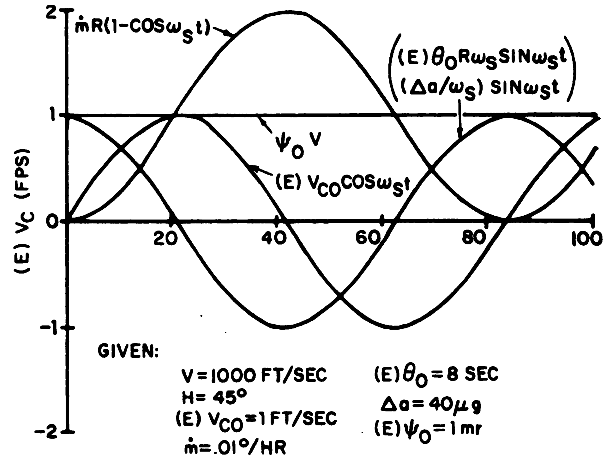

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Figure 9-8.—System velocity errors as a function of time (minutes).

Error in computed velocity due to true vehicular acceleration a_T is

$$(E)V_c = a_T\ (0)$$

The last equation was also derived using differential equations and is important because it shows there is no velocity error due to vehicular acceleration. All the errors are due to erroneous initial conditions and to component errors. Since the two loops are identical, the errors are the same for the north and east Schuler loops.

Figure 9-9 shows that the velocity error due to an initial platform alignment error, Ψ_o, is the error in resolving the vehicle's velocity, V, through the angle $H - \Psi_o$ instead of H. The velocity errors are different in the north and east directions and are functions of the heading H. Assuming Ψ_o to be a very small angle, the velocity errors are

$$(E)V_{cN} = V_{NT} - V_{NP} = \Psi_o\ V \sin H$$

$$(E)V_{cE} = V_{ET} - V_{EP} = \Psi_o\ V \cos H$$

where

$(E)V_{cN}$ and $(E)V_{cE}$ equal computed north and east velocities

V_{NT} and V_{ET} equal true north and east velocities

V_{NP} and V_{EP} equal platform north and east velocities

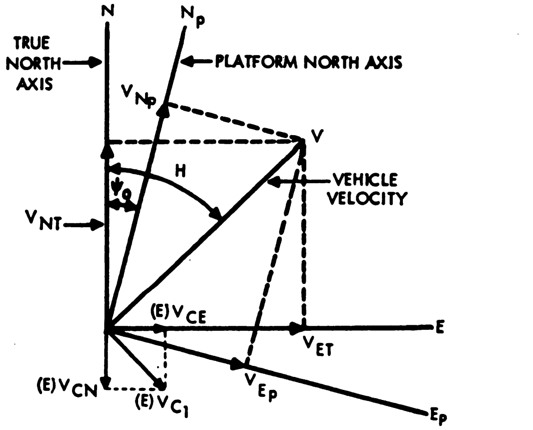

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Figure 9-9.—Effect of platform alignment error.

These two equations can be combined into an error, $(E)V_{cl}$, which is perpendicular to V. That is,

$$(E)V_{cl} = \sqrt{(E)V_{cN}^2 + (E)V_{cE}^2}$$

$$(E)V_{cl} = \Psi_o V$$

This equation, plotted in figure 9-8, becomes a straight line at 1 fps. That is, since vehicle velocity is given at 1,000 fps and Ψ_o is given as 1 milliradian, 1000 × .001 = 1 fps.

The computed position error, $(E)P_c$, can be found for each type of error by integrating the velocity error equation. These errors are plotted in figure 9-10. However, $(E)P_c$, due to initial position error $(E)P_{co}$, is equal to the initial position error; that is,

$$(E)P_c = (E)P_{co}$$

and $(E)P_{co}$ is assumed to be zero in figure 9-10. All other fixed values in figure 9-10 are the same as those given in figure 9-8. As plotted in figure 9-10, an error in computed position $(E)P_c$ due to an error in initial velocity is

$$(E)P_c = \Big[(E)V_{co}/\omega_s\Big] \sin \omega_s t$$

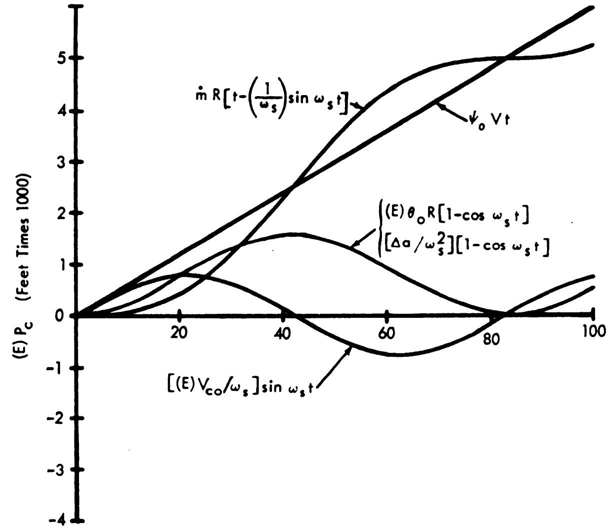

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Figure 9-10.—Systems position errors as a function of time (minutes).

Error in computed position due to a gyro drift rate $\dot{m}$ is

$$(E)P_c = \dot{m}R \left[t - \left(\frac{1}{\omega_s}\right) \sin \omega_s t\right]$$

Error in computed position due to platform tilt error θ_o is

$$(E)P_c = \theta_o R \left[1 - \cos \omega_s t\right]$$

Error in computed position due to accelerometer bias Δ_a is

$$(E)P_c = (\Delta_a/\omega_s^2) \left[1 - \cos \omega_s t\right]$$

The computed north position error $(E)P_{cN}$ due to a platform initial alignment error is

$$(E)P_{cN} = \Psi_o (V \sin H)t$$

and, the computed east position error $(E)P_{cE}$ due to Ψ_o is

$$(E)P_{cE} = -\Psi_o (V \cos H)t$$

Combining these two errors produces an error perpendicular to the path traveled, $(E)P_{cl}$, where

$$(E)P_{cl} = \Psi_o Vt$$

The first five position error equations are both north and east errors, independent of the vehicle's heading; that is, each equation applies to both the north and east Schuler loops. The next two equations are north and east errors, because they are functions of heading. The first five equations and the last equation are plotted in figure 9-10.

Figures 9-8 and 9-10 illustrate one of the major advantages of inertial navigation. Of all the sources of velocity error, only two result in position errors that increase with time—platform initial azimuth alignment error Ψ_o and gyro drift rate $\dot{m}$. Gyro development has reduced drift rates to approximately 0.01° per hour, whereas a platform initial azimuth misalignment of about 2 milliradians is practical.

INITIALIZATION OF INERTIAL NAVIGATION SYSTEMS

In this section, we will look at the techniques and problems involving leveling and aligning inertial navigation systems. Such problems range from the most simple case to the one which is of primary concern to Navy aircraft; that is, the problem of initialization on board an aircraft carrier. While leveling and aligning are related and, in some cases, dependent upon each other, they are treated separately at the beginning to simplify the discussion.

Before continuing, some of the terms used frequently are defined briefly:

Leveling—the process of bringing the stable platform to a position where the accelerometers do not sense any gravity components.

Aligning—the process of bringing the sensitive axes of the platform into a known position in azimuth.

Initialization—the process of bringing the inertial system to a set of initial conditions from which it can proceed with the navigation process. This includes leveling, aligning, setting of initial velocity and initial position, and all additional computations required to start the navigation. In the following discussion, the term will be used to mean leveling and alignment; but, keep in mind that these other initial conditions are implied. They receive less emphasis because they are easily accomplished in the computer.

Slaving—the process of torquing the system gimbals to a position defined by some reference which is external to the system.

Gyrocompassing—the process of self alignment whereby the system achieves azimuth orientation from its own sensors, in the manner similar to a conventional gyrocompass.

The effects of tilt error and azimuth error at the beginning of navigation were examined previously, and a plot of system position errors as a function of time for several values of these initial condition errors is shown in figure 9-10.

It is evident from an examination of these curves and from reading the description of the errors that failure to achieve the proper initial conditions is disastrous to navigational accuracy.

The initialization technique which most of us would first consider is probably one of slaving. The platform gimbals could be rotated to a position defined by some external reference in the same manner as a gun mount is slaved to the stable element of a ship. This method is useful and can be applied to our problem; however, the accuracies we require cause it to be a more critical operation than gun mount stabilization. In addition, while it is quite simple in concept, slaving is more complicated in terms of additional equipment required.

In self initialization, no external directional references are used. The system orients itself by means of computations performed on the outputs of its own sensors—gyros and accelerometers. This method is less complicated in terms of external equipment, but it is more complicated in concept. The following paragraphs are devoted primarily to a description of self-initialization techniques and the problems and errors associated with these techniques.

SLAVING IN A STATIONARY LOCATION

The simplest environment for the initialization of an inertial system is a known, fixed position on the earth. All initial conditions, including level and azimuth, could be available from external sources. A typical example of this environment is a missile launching site. Here, level and azimuth information can be transferred to the platform by optical and electrical transfer methods. These methods require installation of equipment to mechanize this transfer and are best suited to the missile-launching situation.

SELF INITIALIZATION IN A STATIONARY LOCATION

Still simple, but not so well suited to external slaving, is the environment of a known, stationary position not sufficiently fixed to permit installation of slaving equipment. An example of this environment is an aircraft which aligns at any of a number of a stationary positions in or about the hangar and flight apron. This discussion is started with self initialization for systems in this environment from which it can be expanded to encompass the more complex environment of an aircraft carrier. An additional simplification will be introduced here by discussing leveling separately from alignment. Within certain limits, leveling can be accomplished independent of azimuth alignment; and it can be seen later, in the discussion of gyrocompassing, that it is desirable to level the platform before attempting to gyrocompass.

Briefly, review the sensors and connections available on the inertial platform. It contains the accelerometers, which sense acceleration and consequently gravity; gyros, which sense angular rates; a gyro-torquing coil, as part of each of the three gyros on the platform, to torque each gyro individually; and gimbal-torquing motors to torque the platform. The gyro-servo combination is capable of accepting electrical inputs from external sources to torque the platform.

An electrical signal applied to the gyro torquer will cause the gyro to produce an output signal to the platform-torquing servomotor which, in turn, causes the platform to rotate continuously until that signal is removed. All self-initialization schemes make use of this characteristic of the gyro-servo combination. They all operate on some modification of the basic acceleration-leveling scheme, which is described first.

Acceleration Leveling

In its simplest form, leveling is accomplished by taking the electrical output of the accelerometer and applying it to the gyro torquer. As long as the platform is not level, the accelerometer has an output due to the force of gravity. When this accelerometer output is sent to the gyro torquer, it causes the platform to rotate and thus reduce the signal from the accelerometer. When the accelerometer is leveled, it no longer has an output. Thus, the gyro no longer has an output, and the platform remains in this leveled position.

The speed with which this mechanization can level the platform is a function of the gain of the amplifier. Higher gains will cause the platform to torque more rapidly. However, due to the presence of noise in the output of the accelerometer, there are certain limitations to the amount of gain which can be used. If the gain is very high, the platform will respond rapidly to small variations in the output of the accelerometer. A theoretical acceleration-leveling arrangement is shown in figure 9-11.

Figure 9-12 is a block diagram of this theoretical arrangement. All electrical connections are indicated by solid lines and all physical inputs by dotted lines. For example, the gyro output is a physical quantity; i.e., the angle between the platform and the horizontal. When this angle is not zero, it causes gravity to be coupled into the accelerometer input, as indicated by the block labeled "g." This physical input to the accelerometer box causes an electrical output from the accelerometer, which is amplified (– K is the amplifier gain) and used to torque the gyro. Thus we have the closed-loop system. When the platform is level, there is no gravity coupling to the accelerometer; and the loop is in a steady state.

Second Order Leveling

As we have previously seen, the navigational function of the platform requires the acceleration be integrated to obtain velocity before it is fed to the gyro torquer. It would be desirable to maintain this configuration for the leveling loop so there would be a minimum of changes between the leveling system and the navigating system. (See fig. 9-7.)

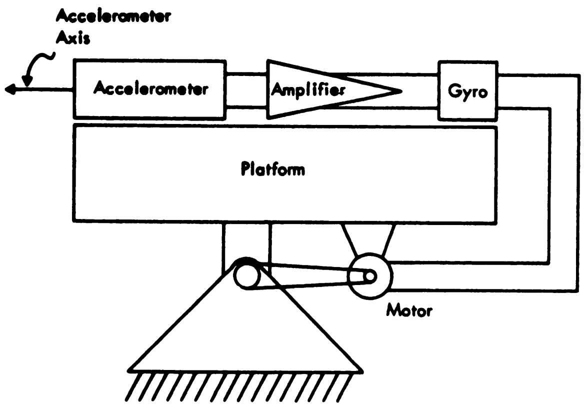

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Figure 9-11.—Functional diagram of acceleration leveling.

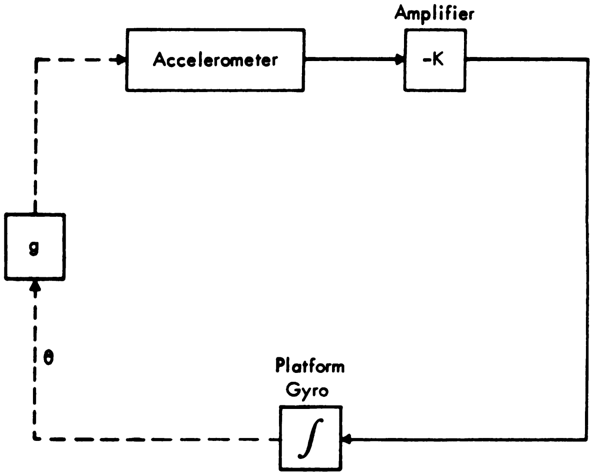

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Figure 9-12.—Block diagram of acceleration leveling or first order leveling.

It would seem that this loop would also level the platform, since the accelerometer output is applied to the gyro torquer through the integrator. Unfortunately, this is not exactly true. The nature of the Schuler loop causes it to act as an undamped pendulum which never reaches a level condition, but it continues to oscillate about that position. Another drawback to leveling in this manner is the sluggish nature of this loop due to the very low gains. The basic period of this loop is 84 minutes—primarily due to the low gain of l/R. Since the purpose here is to establish a vertical, and not to navigate, this term is no longer required to be l/R, but can take on any value desired. In this case, it is desirable to make it large in order to level the platform rapidly. Having altered the sluggish nature of the platform, it is changed to act like a damped pendulum by feeding the integrator output to the accelerometer input. This causes the oscillating platform to come to rest in a level position. The mathematical diagram of this arrangement is shown in figure 9-13. The gain $-K2$ is larger than l/R. The diagram shows, too, that the initial tilt error θ_o

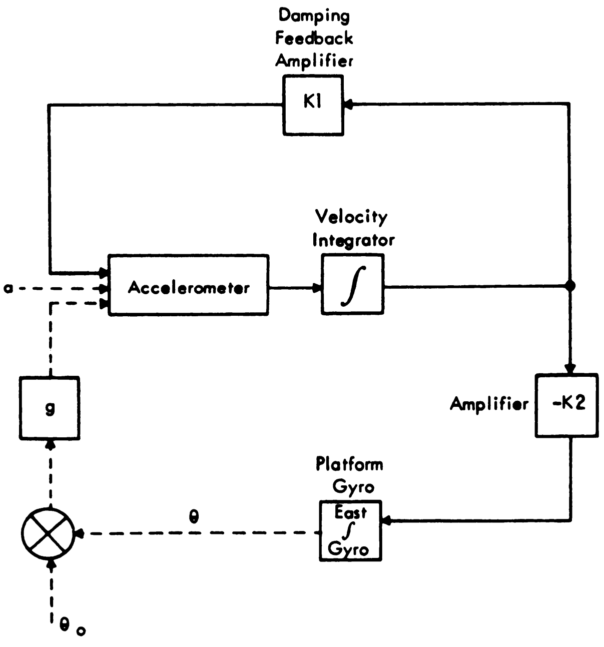

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Figure 9-13.—Second order leveling loop.

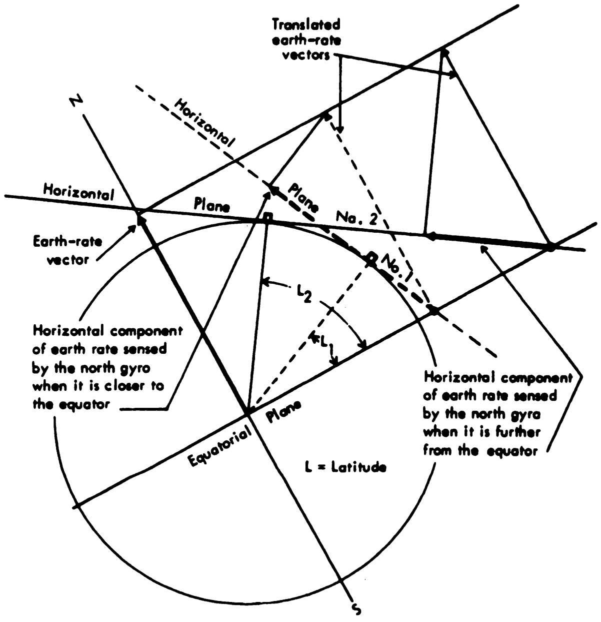
also causes the accelerometer to sense gravity and that the platform tilts until its output θ cancels θ_o. At that time the accelerometer will be level.

Gyro as a Rate Detector

Before we look at gyrocompassing, the rate measuring capability of a gyro should be clarified. The gyro detects rates about its input axis. The platform gyro-vector orientation is shown in figure 9-3. If the axis of the rotation is not parallel to the gyro input axis, the gyro will not sense the entire rate, but only some portion of it which is proportional to the angle between the rate rotation axis and the gyro input axis. This can be easily represented by using vectors to describe the rates. A vector representation of a rate will be directed along the axis of rotation, with its length proportional to the rate and its direction according to the right-hand rule, which is similar to the one used in describing magnetic fields about a wire. If the right hand is wrapped around the axis with the fingers indicating the direction of rotation, the thumb points in the direction of the rate vector. Rate components of this vector along other axes at angles to the rotation axis will be equal to the rate times the cosine of the angle between the axes. Figure 9-14 shows how this works for the earth-rate component in the horizontal plane. This shows that a gyro with its input axis in the horizontal plane and pointed north will sense a rate equal to earth rate times the cosine of latitude. That is, when the north gyro is at the equator, it senses the entire earth rotation rate; but, when it is at the north pole, it senses none.

Gyrocompassing

With this concept in mind, a discussion of azimuth alignment by a method known as gyrocompassing should follow. It is so called because the basic technique is exactly the same as the one used in a conventional ship's gyrocompass. The vector relationship for earth rate in the horizontal plane was shown in figure 9-14. Now examine


Translated earth-rate vectors
N
Horizontal
Plane
No. 2
Horizontal
Plane
No. 1
Earth-rate vector
L_2
L_1
Horizontal component of earth rate sensed by the north gyro when it is closer to the equator
Equatorial
Plane
L = Latitude
Horizontal component of earth rate sensed by the north gyro when it is further from the equator
S

223.190
Figure 9-14.—Horizontal component of earth rate.

figure 9-15, which is a top view of the horizontal plane. The coordinate axes labeled X and Y are the principal axes of a platform misaligned from north by an angle Ψ. Each of these axes is the sensitive axes of a gyro: Y is the north gyro and X is the east gyro. (As mentioned previously, the north gyro has its input axis running north-south and would sense the east-west rotation of the earth.) First simplify the earth-rate vector by letting $\Omega_{IE} \cos L = \Omega_N$. Then, resolving it into the X and Y axes gives the two components shown, $\Omega_N \cos \Psi$ along the north gyro axis and $-\Omega_N \sin \Psi$ along the east gyro axis. It is desired to rotate the platform in azimuth until Ψ is zero. At that time the two components will be Ω_N along the north gyro axis and zero along the east gyro axis. This is a situation made to order for a servomechanism approach. The east gyro is an error sensor which detects zero error when the platform is in the desired position. Practically all the necessary components are in the second order leveling loop. If the second order leveling loop is not oriented with the east gyro axis pointed exactly east, this gyro will pick up an earth-rate component. For the leveling loop to reach a steady state, this gyro input must be canceled.

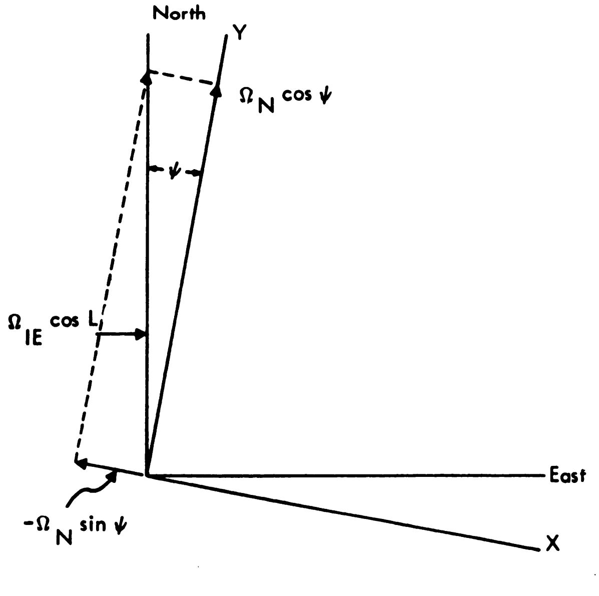


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Figure 9-15.—Components of earth rate in the horizontal plane.

The gyrocompassing feature is added to the second order leveling loop in figure 9-16. The integrated acceleration does not reach zero but rather a value equal and opposite to the earth-rate input to the gyro. This value can be used as the error signal for azimuth alignment. The signal is amplified with a gain of $-K3$, and used to torque the azimuth gyro and, consequently, the platform; that is, the azimuth gimbal torquer moves through an angle Ψ until it cancels out the initial alignment error angle Ψ_o. As the east gyro axis becomes perpendicular to the earth-rate vector, the output of the velocity integrator drops to zero; and the platform stops torquing when the east gyro axis is pointed directly east and the platform is level. The azimuth gyro is represented as an integrator with an output of platform azimuth error Ψ. Remembering that the sine of a small angle is approximately equal to the angle in radians, the earth-rate input to the east gyro can be simplified; it is shown as $\Omega_N\Psi$. When the loop reaches steady state, the east gyro has zero input because Ψ is equal to zero; the azimuth gyro has no input because the indicated input to $-K3$ is zero. In addition, the platform is level because there is no signal feed back through K1.

INITIALIZATION ON A MOVING BASE

At this point there is an established system which aligns satisfactorily in a stationary environment. Now go back to the simple first

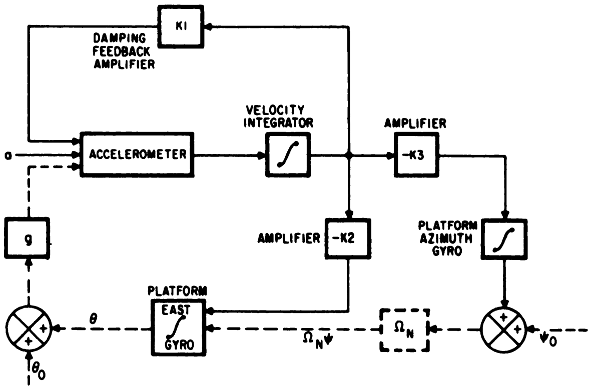

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Figure 9-16.—Gyrocompassing loop.

order leveling loop (fig. 9-12) and examine its performance on an accelerating base such as an aircraft carrier.

Acceleration Leveling

Leveling was accomplished by nulling the accelerometer output. If the platform is on a vehicle which is accelerating (an aircraft carrier in a turn), there will be an input to the accelerometer in addition to the gravity terms caused by tilt. These will cause outputs, which look like tilts, at the level position of the accelerometer; that is, an acceleration of 0.001 g will look like a tilt of 3.44 minutes of arc. The simple acceleration leveling scheme will rotate the platform until the accelerometer has zero output, whether these outputs are from tilts or accelerations of the base. The 0.001-g input mentioned will cause a tilt error of 3.44 minutes of arc. An aircraft carrier in a turn of 0.5 degree per second at 25 knots is accelerating at a rate of 0.11 g toward the center of the turn. You can see that this causes an intolerable tilt error. One way to eliminate this problem is to introduce a term which compensates for the acceleration. This would require some independent device to measure the acceleration. The achievement of an external measure of acceleration without the use of another inertial system presents so many problems that first order leveling on the moving base is abandoned, since there are easier ways to solve the problem.

Second Order Leveling

The second order leveling loop also provides leveling problems during accelerations. The velocity integrator output changes during accelerations and disturbs the platform level through the K1 feedback. In addition, the aircraft carrier's velocity over the earth introduces rate inputs to the gyros which cause steady state platform tilts. The tilts associated with these effects are too large for satisfactory platform initialization and must be removed by some form of compensation. Both of the disturbing errors are velocities; therefore, they can be compensated for by introducing velocity from an external source, such as the ship's electromagnetic log (EM log).

The ship's EM log is a speed-measuring device which makes use of Lenz's law to measure the speed of the ship. Lenz's law defines the nature of electric currents generated in conductors moving in magnetic fields. In the case of the EM log, a sensor called the sword is lowered into the water. As sea water (which is a conductor) flows around the sword, a current is induced in the sea water. This current causes a secondary magnetic field which distorts the primary field of the log. Measurement of the field distortion gives an indication of the ship's speed through the water.

The EM log has two major sources of error: First, it measures only speed through the water; consequently it ignores any ship velocity due to ocean currents. Secondly, it measures only the local longitudinal component of velocity. As the ship slips sideways in a turn, the alterations in local flow at the log cause it to have errors on the order of 2 to 3 knots.

The reference velocity is introduced as shown in figure 9-17; that is, it cancels the steady state value of platform velocity at the velocity

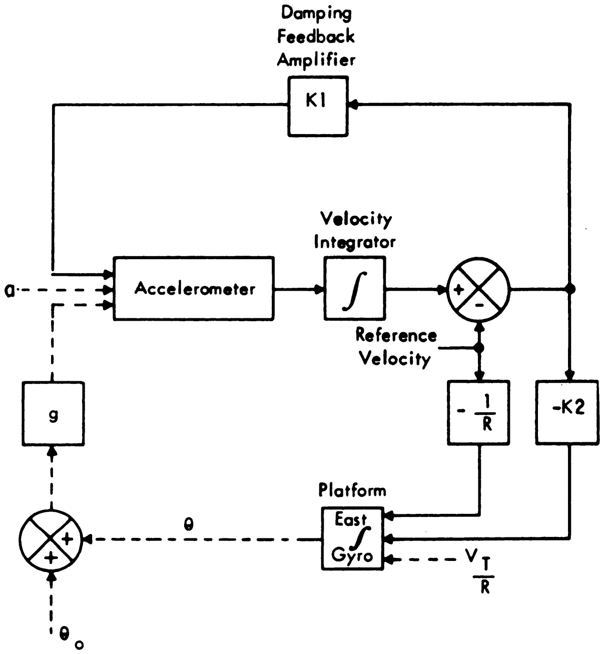

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Figure 9-17.—Second order leveling loop with reference velocity.

integrator output so that the feedback through K1 and the feed forward through −K2 are nearly zero in a steady state. The rate due to the aircraft carrier's velocity over the earth is computed and used to compensate the level gyros. Neglecting errors in reference velocity, the system levels as accurately as a second order loop at a stationary location.

Examine the effects of errors in the reference velocity. There are two major types of error, and they cause two very different problems. The constant error, which is due to ocean current and EM log bias, causes a steady state tilt error just as a gyro drift rate does. This error would not substantially change the gains used in leveling at sea. The other source of reference velocity error is the transient and oscillatory error in the EM log. The most troublesome error in the log is the inaccuracy of its output during a turn. The errors thus introduced to the platform cause it to take up transient tilts with peak values much larger than the steady state errors. Even if the ship is not in a turn, there is continuous oscillatory "noise" on the EM log due to slight wander of the ship about its straight course and to the ship's pitch and roll motion. In order to minimize the transient excursions of level, the gains must be made lower. Making gains lower has the detrimental effect of lengthening the time required to remove initial errors. The gain selection then becomes a compromise between fast elimination of erroneous initial conditions and attenuation of transient errors. This defines the basic problem of aligning and leveling at sea, which becomes more severe as azimuth alignment is attempted.

Gyrocompassing

The gyrocompassing loop develops from the second order leveling loop, just as it did on the stationary base. In this case the velocity difference signal is used, through the −K3 amplifier, as the torquing input to the azimuth gyro. The reference rate to the east gyro, through the −*l*/R amplifier, should compensate for the rate due to velocity of the aircraft carrier and leave the earth-rate error signal as the primary gyrocompassing signal. This loop is shown in figure 9-18.

In figure 9-18, an additional factor has been added to the earth-rate term. This is the V_E/R term, which reflects the additional rate due to east velocity. It has no bearing on steady state error, but it does have the effect of changing the loop gain as a function of east velocity.

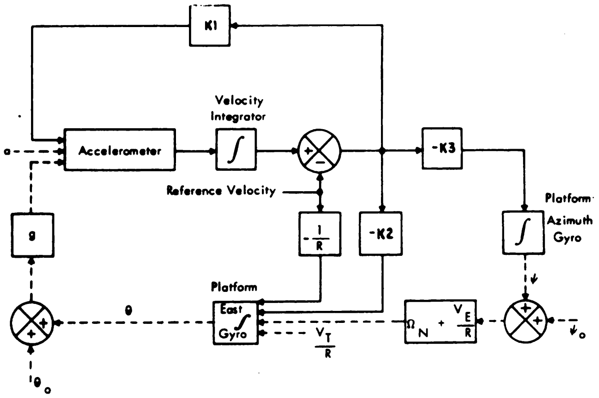

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Figure 9-18.—Gyrocompassing loop with reference velocity.

The gyrocompassing loop is the same as the one developed previously, with the addition of the reference velocity inputs. The same steady state results hold for this loop. It will level accurately, except for error due to accelerometer bias; and it is not sensitive in level to rate errors to the east gyro. Azimuth accuracy is a function of rate errors to the east gyro; therefore, the bias errors in the reference velocity will add to the east gyro drift in causing azimuth error. The azimuth error is a function of latitude; it will be about 4 minutes for each knot of north reference error in mid-latitudes.

The errors just described are steady state errors. Just as in the case of leveling, transient velocity errors are severe problems. Any reference velocity errors appear immediately at the azimuth gyro torquer, so that any errors will cause the platform to be torqued erroneously in azimuth. In order to hold this azimuth error to a small value, the torquer gain −K3 must be kept low. As in the level loop, any reduction of gain increases the time for removal of initial condition errors. Gains which permit reasonably accurate alignment during turns, using the EM log, require gains low enough that 30 to 45 minutes of alignment time will be required to reduce the initial condition errors to the desired values. Even with these low gains, large turns at the end of alignment can cause intolerably large errors in azimuth.

Inertial Source of Reference Velocity

One method of solving this problem lies in the use of another aligned inertial system to supply the reference velocity to the aligning system. The problem with the EM log was two-fold: It did not measure all velocities (ship motion), and it was in error during turns. The inertial reference source does not have these drawbacks. It measures all velocities at the point where it is mounted, and it has no errors which are a function of turns. The worst problem of the inertial system is log term bias errors due to platform drift and initial alignment errors. If the inertial system is aligned at sea, it will have a bias error equal to EM log bias in its velocity output. However, the errors due to long-term biases are small compared to the transient errors; and the accuracy of inertial systems on a short-term basis makes these transient errors small. In this respect, the inertial source of velocity holds forth promise of shortening alignment times, but gyrocompassing is still limited in the sea environment because this environment is inherently noisier and requires lower gains to attenuate the noise. Pitch, roll, and yaw motions cause remote parts of the ship to have sizable velocities with respect to the reference location. To realize the full value of an inertial source, these relative velocities must be computed and added to the reference system output velocities. The accuracy with which this can be done limits the maximum gains which can be used.

Rough Leveling

The sea environment adds one more problem to the alignment process. Since platform tilt enters the gyrocompass loop as part of the apparent azimuth alignment error, any initial tilt at the start of gyrocompassing will result in an azimuth response. In fact, the loop is quite sensitive to this tilt with a peak azimuth transient error reaching as high as 20 times the initial tilt error. At sea, where sea motion causes the vehicle to be oscillating about the vertical, it is difficult to initialize the level accurately. It may be off 3 or 4 degrees, causing a peak azimuth transient of 60 to 80 degrees. One way to avoid this problem is to level roughly with the second order loop before starting the gyrocompass torquing. In 2 or 3 minutes, the platform can be leveled to less than 10 to 20 minutes-of-arc error. Subsequent gyrocompassing is then easier because of the elimination of the large transient.

Now, let us review the requirements and problems of shipboard initialization. The accelerations of the ship create inputs to both accelerometers and gyros which prevent the techniques of stationary leveling from working properly. These accelerations must be compensated by the introduction of a reference velocity. The EM log is a fairly good source of reference velocity, but it has its largest error during turns—which is also the time of highest acceleration. To reduce these errors, system gains must be made low, resulting in long alignment times. Reference velocity from an inertial system has better characteristics and will permit shorter alignments. However, the sea environment is always a difficult environment for gyrocompassing, and there are practical limits to short alignment even with an inertial source of reference velocity. Alignment times of 5 minutes and less will require more exotic methods than gyrocompassing.

DOPPLER NAVIGATION

A simplified explanation of the Doppler principle as it applies to Doppler radar navigation is presented first to provide the basis for understanding its application in the Radar Navigation Set AN/APN-122(V). A general theory of system operation follows based on the methods employed in the AN/APN-122(V) system. These methods are essentially the same as those used in the AN/APN-153(V) and AN/APN-190(V) systems described later in the chapter.

DOPPLER RADAR PRINCIPLES

As opposed to search- and acquisition type-radar, which employs pulse-type RF transmission, the Doppler radar employs CW RF transmission in conjunction with the "Doppler effect." It should be remembered that pulse-type radar determines distance to target by measuring the period between transmission of a pulse and receipt of the reflected pulse, while the CW Doppler radar senses velocity by measuring a proportional shift in frequency of the reflected signal. This frequency shift is the "Doppler effect." In operation, the airborne CW Doppler radar transmits fixed-frequency RF signals as two or more narrow beams. The beams are transmitted earthward and displaced laterally and longitudinally at fixed and equal angles. The same airborne set receives a portion of the earth-reflected CW signals, each of which has undergone a Doppler frequency shift due to the Doppler effect. By continuously mixing the received energy with samples of the transmitted energy, followed by electronic detection, velocity proportional difference frequency signals are extracted. These are the Doppler signals, and they contain composite velocity information. Since they are of audio frequency, they may be amplified, electromechanically or electronically tracked, and compared with pitch, roll, and altitude rate information to derive the individual components of the aircraft's velocity relative to the axes or relative to the earth's surface.

DOPPLER EFFECT

Electronically, the Doppler effect is the apparent increase or decrease in frequency in a received signal resulting from the movement of either the transmitter or receiver, or both relative to each other, or from the simultaneous movement of a combined transmitter-receiver relative to each other, or relative to a fixed reflecting surface. Disregarding angular motion for the present, the magnitude of the frequency shift is directly proportional to the closing or receding velocity along a straight line distance between the transmitter and receiver, or between the combined transmitter-receiver and fixed reflecting surface.

The Doppler effect is best explained with the aid of figure 9-19. Assume three conditions of flight relative to transmitter T, represented on figure 9-19 by aircraft A, B, and C.

Aircraft A—heading on a straight line course toward T and flying at a constant speed of approximately 11 wavelengths per second and covers the distance from point X to X′ in 1 second.

Aircraft B—heading on a straight line course away from T and flying at the same constant speed as A, covers the distance from Y to Y′ in 1 second.

Aircraft C—heading on a straight line course toward T and flying at a constant speed approximately 1 1/2 times the speed of A, covers the distance from Z to Z′ in 1 second.

During all three preceding conditions, transmitter T is transmitting a VHF, CW signal of "f" cycles per second. Therefore, each distance from X to X′, Y to Y′, and Z to Z′ is equal to a specific number of wavelengths at "f" frequency.

Now assume that each aircraft, A, B, and C, is equipped with a relatively broadband receiver capable of accepting signals at frequencies higher or lower than transmitted frequency "f." During the 1-second interval in which A is flying from point X to X′, "f" number of cycles of the signal from T reach point X. Since A is advancing in a straight line toward the signal source, it receives not only the "f" number of cycles it would receive if stationary for 1 second over point X, but simultaneously receives additional wavelengths of the signal en route between point X′ and X. Therefore, aircraft A receives a signal which is of apparent higher frequency than that emitted by the transmitter.

The magnitude of the preceding frequency shift is proportional to the speed of the aircraft toward T and inversely proportional to the frequency of the transmitted signal. The direction of frequency shift is dependent on the direction of flight relative to the signal source. The effect of flight direction and speed on the direction and magnitude of frequency shift is illustrated by

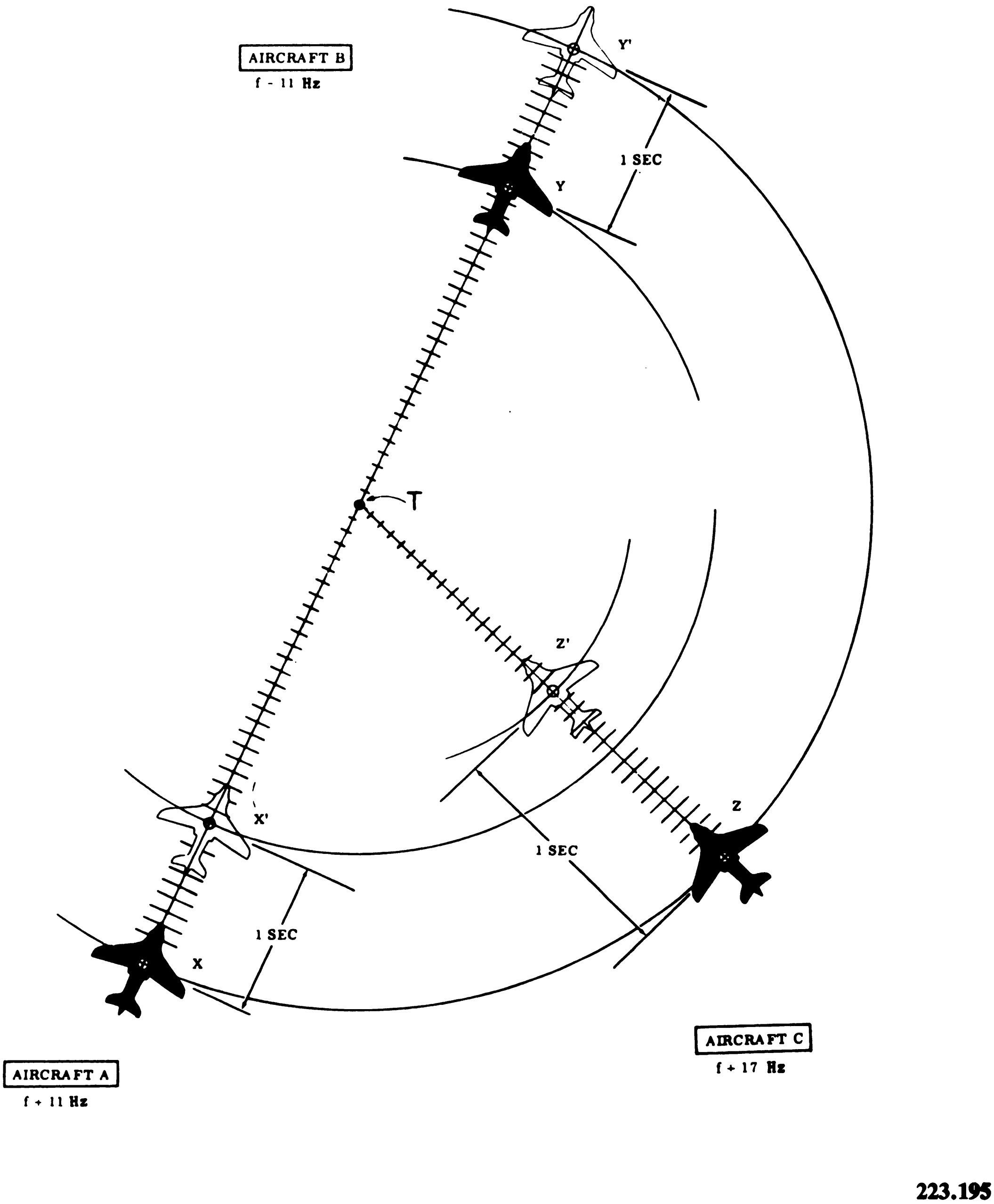
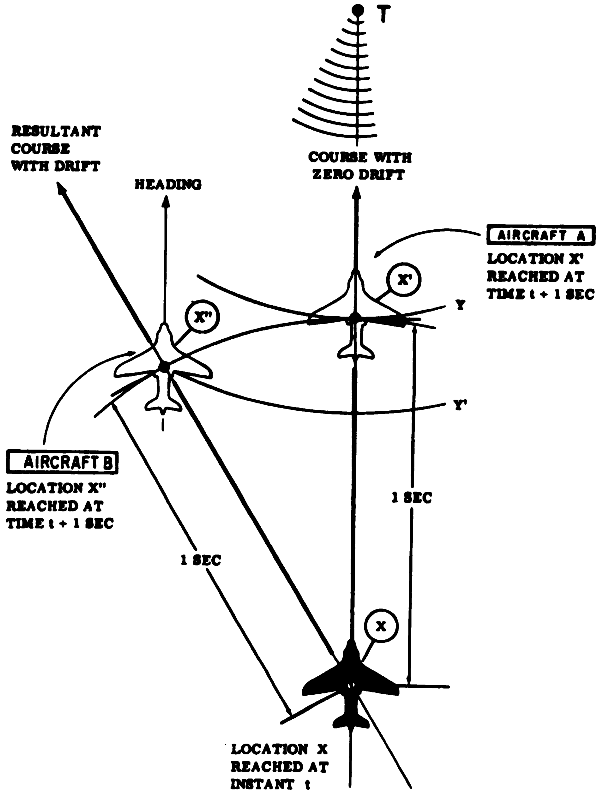


Figure 9-19.—Doppler frequency shift, stationary transmitter, airborne receiver.

aircraft A, B, and C on figure 9-19. Since aircraft B is flying away from the signal source at a speed equal to the speed of A, the apparent frequency is lower than the transmitted signal but equal in magnitude to the apparent frequency received by A. Since aircraft C is flying in the same direction, but approximately 1 1/2 times the speed of A, the frequency received by C is also apparently higher than the transmitted signal, but greater than that received by aircraft A. The apparent frequency shift is the Doppler effect.

When an aircraft sets its heading toward a fixed ground transmitter but experiences drift, which if not corrected, results in a heading as


T
RESULTANT COURSE WITH DRIFT
HEADING
COURSE WITH ZERO DRIFT
AIRCRAFT A
LOCATION X' REACHED AT TIME t + 1 SEC
X'
X"
Y
Y'
AIRCRAFT B
LOCATION X" REACHED AT TIME t + 1 SEC
1 SEC
1 SEC
X
LOCATION X REACHED AT INSTANT t

223.196
Figure 9-20.—Effect of drift on Doppler frequency shift.

illustrated in condition B (fig. 9-20), the Doppler frequency shift is proportional to the amount of drift, as illustrated.

The following conditions on figure 9-20 are assumed:

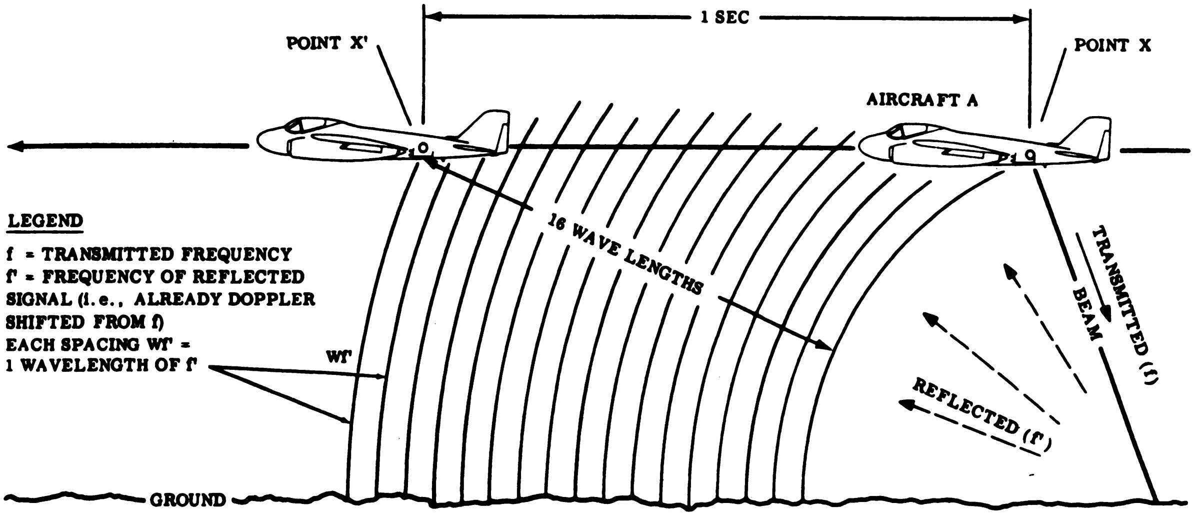
Aircraft A—flying with zero drift and headed straight toward transmitter T.

Aircraft B—flying at the same speed as A but drifting past the transmitter.

In the interval of 1 second, aircraft A has approached closer toward the transmitter than aircraft B. The evidence can be seen when comparing the arcs scribed at Y and Y '. Because of the faster rate of approach to the transmitter, aircraft A receives more cycles of the transmitted frequency per unit of time than aircraft B. This results in an apparent increase in frequency received by aircraft A over that received by aircraft B. The difference in the Doppler effect on received frequency of zero drift and drift conditions suggests a means of determining drift angle.

TWO-BEAM SYSTEM—AN/APN-122(V)

The Doppler frequency shift previously described also occurs when the transmitter and

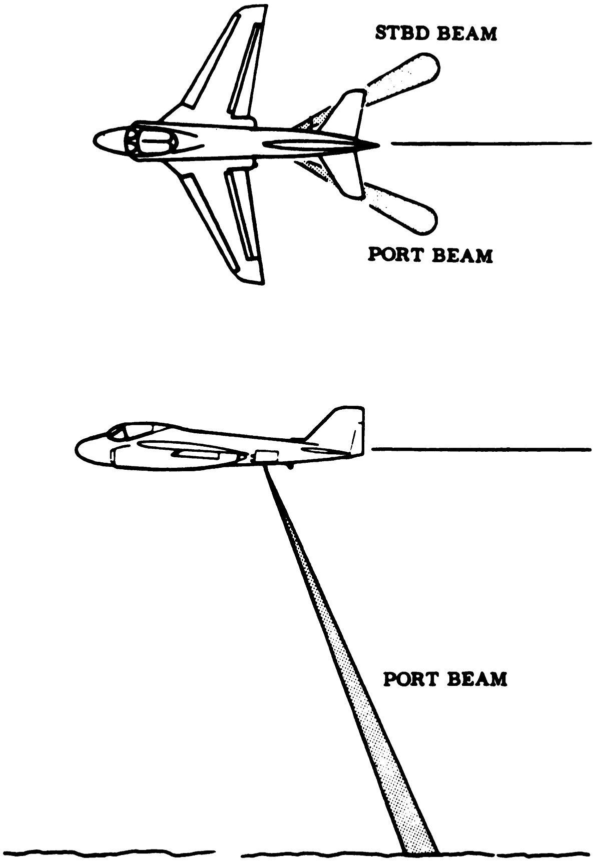

1 SEC
POINT X'
POINT X
AIRCRAFT A
LEGEND
f = TRANSMITTED FREQUENCY
f' = FREQUENCY OF REFLECTED SIGNAL (i.e., ALREADY DOPPLER SHIFTED FROM f)
EACH SPACING Wf' = 1 WAVELENGTH OF f'
Wf'
16 WAVE LENGTHS
TRANSMITTED BEAM (f)
REFLECTED (f')
GROUND

223.197
Figure 9-21.—Frequency shift: airborne transmitter-receiver with oblique beam.

receiver are in motion together, as when carried in an aircraft, and received signals are signals reflected from a fixed point on the earth's surface. The receiver will sense a Doppler frequency shift that is directly proportional to the speed of the aircraft. The ratio of frequency shift to ground speed will be twice that illustrated in figure 9-19 and 9-20, since a proportional shift occurs in the signal on its way to the earth's surface and occurs again to an equal degree, during straight line flight, in the signal returning to the receiver. To obtain the largest possible frequency shift, you must focus the transmitted beam toward the earth at that angle which will yield the largest ratio of change in distance between the transmitter-receiver and the earth's surface. The desired rate of change is obtained when the transmitted beam is inclined toward, or away from the direction of the aircraft's heading. Figure 9-21 illustrates the Doppler shift sensed by an airborne transmitter-receiver in which the beam is focused obliquely downward and aft of the aircraft's longitudinal axis.

In figure 9-21, aircraft A flies from point X to X′ in 1 second. The signal f' Hz is reflected from the ground toward the receiver. Each second the receiver recedes from the reflected signal, a distance equal to 16 wavelengths of frequency f' is traveled. Because each wave must catch up with the receiver, the time between each of the reflected waves is increased and therefore delayed in arrival which, in effect, is as if the reflected signal frequency f' had decreased to $f' -$ Hz.

To sense drift and heading velocities simultaneously, two transmitter beams are utilized which are directed laterally relative to aircraft heading as well as earthward and aft. In Radar Navigation Set AN/APN-122(V), the two beams are directed symmetrically, one to port and one to starboard of the aircraft's longitudinal axis. The orientation of the transmitter beams relative to the horizontal and vertical planes is illustrated in figure 9-22.



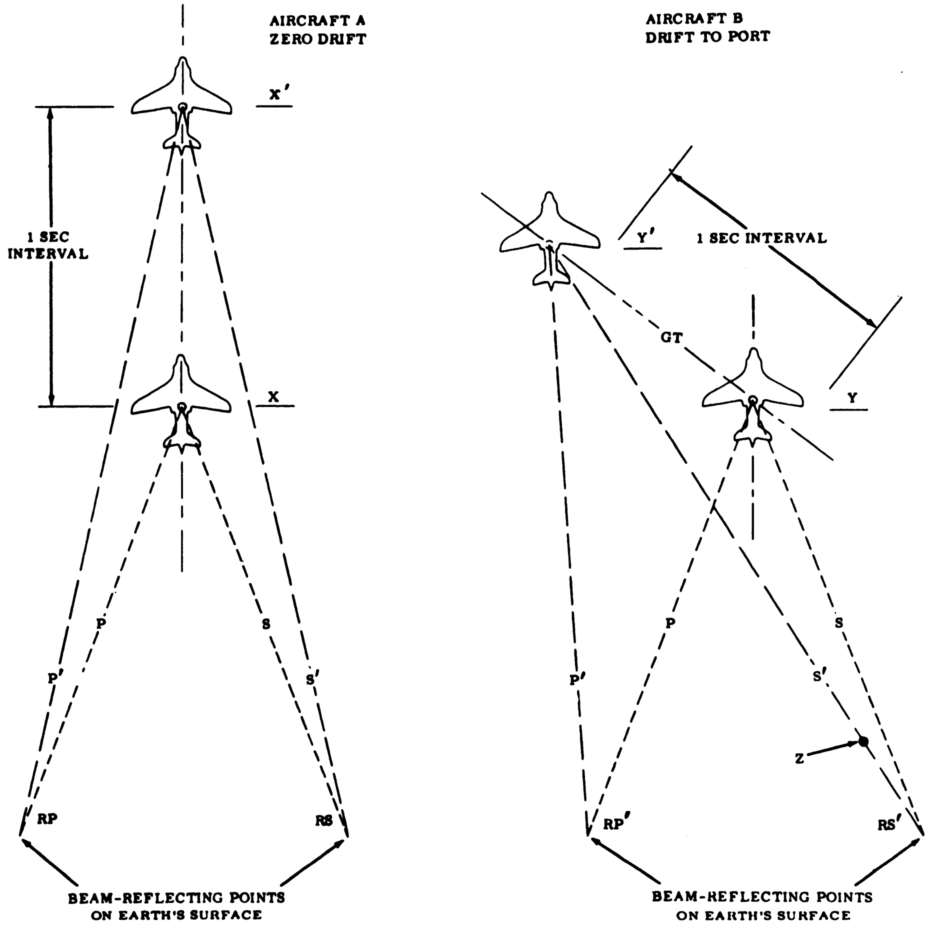
223.198

Figure 9-22.—Beam orientation of Radar Navigation Set AN/APN-122(V).

Effect of Drift on Frequency

The Doppler effect in an aft-oriented dual beam system is illustrated in figure 9-23. Assuming the aircraft is not drifting, simultaneous radiations of each beam are reflected back to the aircraft from separate points on the earth's surface. The time in transit of the microwave energy in each beam is a direct function of the aircraft velocity. If they could be seen, the continuous waves of transmitted energy would form dual traces across the earth's surface; these traces comprising successive instantaneous points of reflection.

In figure 9-23, the port transmitted beam P has a rate of travel equal to its corresponding starboard transmitted beam S. Therefore, points RP and RS and RP′ and RS′ are the instantaneous points of reference for determining the rate of travel by the received beams of aircraft A and B, respectively. In the zero drift condition illustrated, aircraft A maintains heading H from X to X′ for 1 second. The rate at which A recedes from reflecting points RP and RS is equal; therefore, the effective wavelength of the RF energy in



223.199

Figure 9-23.—Effect of drift on frequency shift in dual beams.

beams P ′ and S ′ is equal. Since Doppler frequency shift is proportional to the relative velocity between the reflector (earth) and the receiver, the Doppler frequency shift in beams P ′ and S ′ of A is equal. In the drift to port condition illustrated, aircraft B encounters drift forces and covers ground track GT in 1 second. The rate at which B recedes from reflecting point RS ′ is greater than the rate at which it recedes from point RP ′. Therefore, the distance that beam S ′ of aircraft B travels in 1 second is greater than its associated beam P ′ in equal time by the distance from point Z to RS ′. Since the rate of travel of effective wavelength for beam S ′ is greater than beam P ′ in a port drift condition, the Doppler frequency shift is greater in S ′ than in P ′. If the drift were to starboard instead of port, the largest Doppler frequency shift would occur in the port beam.

From the foregoing discussion, you can see that by using dual oblique beams, the direction of drift can be derived from the received beam which registers the least frequency shift. The velocity of drift can be computed from the difference between the magnitude of frequency shift in each beam, and ground speed can be computed from the sum of the magnitudes of frequency shift in each beam. The preceding is, in general, the method used for deriving direction and velocity of drift and ground speed in radar navigation sets.

Functional Theory of the Radar Navigation Set

Two narrow beams of continuous microwave energy are transmitted by the transmitter-receiver and focused obliquely toward the earth. The beams are displaced laterally, one to port and one to starboard, and aft (fig. 9-21). A portion of the transmitted energy from each beam is reflected from the earth's surface at an angle sufficient to be intercepted by the receiving portion of the transmitter-receiver antenna. Each received CW signal is mixed with continuous samplings of the transmitted signal within the waveguide assembly of the antenna, then coupled to their respective port or starboard crystal detectors. The resultant difference frequency output signal (f_{dp} and f_{ds}) of each detector is proportional to the aircraft's velocity along the port and starboard beam axes, respectively. These Doppler signals are of equal frequency as long as the aircraft maintains a straight line heading with no pitch or roll. If the aircraft drifts to port or starboard, its drift is sensed as a decrease in Doppler frequency derived from the beam that is focused in the direction of drift, and an increase in Doppler frequency derived from the beam focused opposite to the direction of drift.

Due to the lobe pattern of the transmitted beams, the reflected energy of each beam comprises a narrow band of frequencies rather than a single frequency. The resultant narrowband Doppler difference signals (port Doppler frequency and starboard Doppler frequency) are fed from the port and starboard crystal detectors, respectively, to the dual channel amplifier assembly where each is amplified under automatic gain control and then fed to the signal data converter.

Using what are initially only noise inputs, the signal data converter initiates a search function to acquire well-defined Doppler signals in both port and starboard channels. Simultaneously this converter supplies gain-increasing AGC feedback voltages to the amplifier assembly and a memory signal to be used in the ballistics computer. This memory signal is also used to cause an indicator lamp to come on, indicating that the signal data converter is operating in the search mode. When a satisfactory Doppler signal is acquired, the signal data converter will lock on and track the center of each Doppler energy spectrum and convert these signal frequencies to rate-proportional pulse outputs. The memory signal is cut off and the indicator or lamp goes out. These rate-proportional pulse outputs, which are representative of aircraft velocity data, are then routed to the ballistics computer.

FOUR BEAM SYSTEM—AN/APN-153(V)

The AN/APN-153(V) is a lightweight, miniaturized ground speed and drift angle measuring system which is designed to satisfy the navigational requirements of modern military aircraft. It uses Doppler pulsed radar techniques to measure ground speed and drift angle directly, continuously, and accurately. Its small size and light weight permit it to be easily installed in almost any fixed-wing aircraft.

Operating Principles

The AN/APN-153(V) emits short pulses of microwave energy, so the transmitter is not operative while an echo is being received. Therefore, in a single-beam radiation pattern there would be no second frequency with which to compare the echo. However, two beams—one projected dead ahead and the other directly behind—would experience equal but opposite Doppler shifts. In this event, one-half the difference between the two echo frequencies is the Doppler shift of either beam, and is proportional to ground speed. This condition assumes no drift. If drift were present, the two-beam system described above would not detect it when used with pulsed beams. Antennas radiating to the left and right would detect sideways motion, but not fore and aft motion.

In order to make simultaneous measurement of both ground speed and drift angle, the AN/APN-153(V) uses a modification of the two-beam pattern. The vicinity of the aircraft is divided into four quadrants—left forward, left rearward, right rearward, and right forward. (See fig. 9-24(A)). Simultaneous beams are radiated into diagonal quadrants with switching of the quadrants at regular intervals.

When there is no drift, the ground track and aircraft heading coincide. In this condition, as shown in (B) of figure 9-24, the radiation pattern is symmetrical about the axes of the aircraft, and the left and right beams are at the same angle from ground track. The Doppler shift is equal in the beams.

When the antenna is not aligned with ground track (fig. 9-24C)), an angle exists between the antenna axis and ground track, and the beams experience unequal shifts. The difference frequency resulting from one pair of beams is higher than that from the other. As the switching action occurs, this difference is processed as an error signal which, through servo action, drives the antenna into alignment with the ground track.

When the antenna is aligned with ground track, the angle between the antenna axis and the aircraft heading represents the drift angle. Through a synchro system, this information is supplied to the computer along with the ground speed data.

EIGHT-BEAM SYSTEM—AN/APN-190(V)

The Doppler Radar Navigation Set AN/APN-190(V) is an airborne ground speed and drift measuring system using the Doppler principle to extract data from reflected signals. A lightweight system, operating on a frequency of 13.325 (±0.05) GHz, precisely measures, processes, and indicates ground speed and drift angle information aboard aircraft. The AN/APN-190(V) is essentially a solid state system of high operational reliability that requires minimum maintenance. It is used in conjunction with a navigation/weapon delivery computer, inertial measurement system, and a head-up display set.

In measuring the ground speed and drift angle of an aircraft, the system transmits narrow beams of electromagnetic energy downward from an antenna stabilized in pitch, roll, and azimuth to illuminate small areas on the earth's surface. A portion of the transmitted energy is reflected from the surface, received, and processed by the system to determine the Doppler frequency shift.

Operating Principles

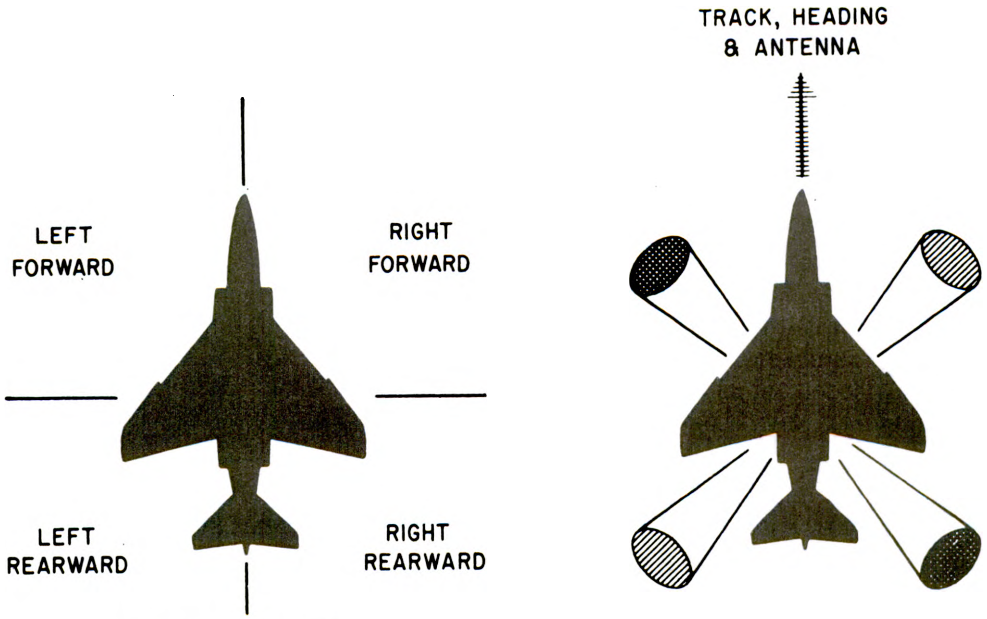
The AN/APN-190(V) radiates a four-beam pattern consisting of two beam-pairs alternately switched from left to right of the aircraft fore-aft axis. Frequency shifts occurring in each beam are proportional to the components of the aircraft's forward and lateral velocity along the respective antenna beam. The frequency shifts, which are due to the Doppler effect, are detected by mixing a portion of the transmitted signal with the received signal and detecting the audio beat frequency.

After detection, the Doppler signals are fed to ground speed and azimuth tracking circuits. These circuits convert the signals into voltages proportional to ground speed and azimuth. Outputs proportional to these voltages are provided in proper electrical form to drive the appropriate auxiliary equipment.

Equipment Theory

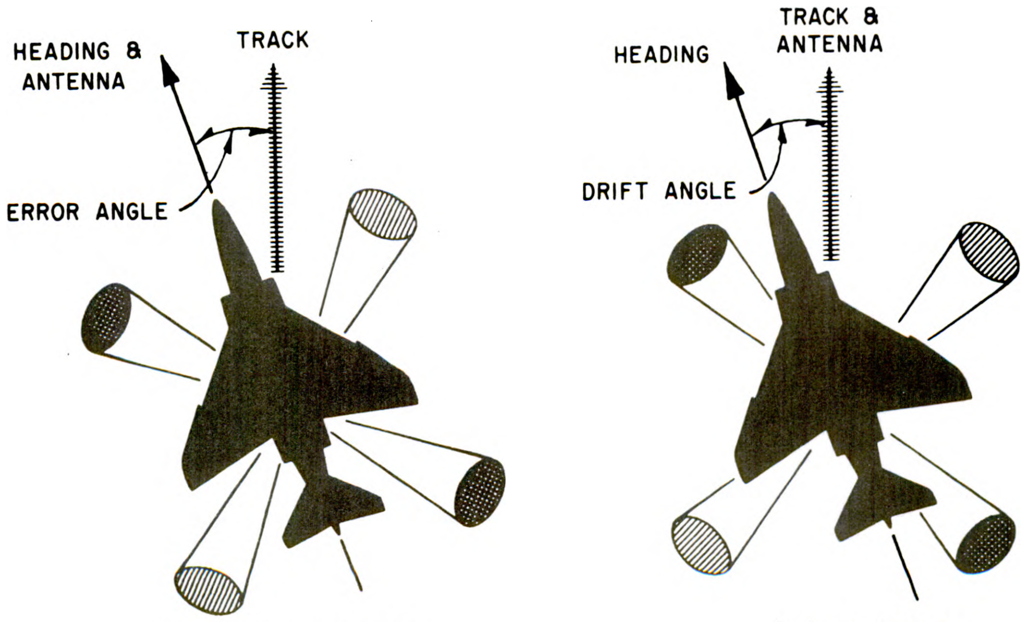
The magnetron in the radar transmitter generates 200-volt pulses of RF energy at a PRF of 80 to 120 kHz with an average power of 10 watts. The magnetron output is applied to a crystal switch which passes the magnetron pulses to a duplexer to route the microwave energy to a waveguide assembly. During the transmit cycle, the receiver crystal switch is closed, thus minimizing coupling of transmitted energy into the receiver. The duplexer permits the same antenna to be used for both transmitting and receiving and isolates the receiver from the transmitter. It also couples the transmitted signal to the waveguide assembly and, during the receive cycle, couples the return signal from the waveguide to the receiver switch. The waveguide couples transmitter RF energy to the antenna. Four radiating elements composed of a J-band waveguide, four reflectors, and a waveguide flange complete the antenna array.

When the set is transmitting, the generated RF energy is applied through the crystal switch to the duplexer and waveguide assembly, coupling the energy to the antenna so that the switching and array combination generates eight beams of



(A) QUADRANTS

(B) ALIGNED
NO DRIFT



(C) NOT ALIGNED

(D) ALIGNED
DRIFT CORRECTION

229.193

Figure 9-24.—Four-beam pattern, using two-beam transmission.

energy. (See fig. 9-25.) The beams are radiated two at a time in the following order: Front right (A) and aft left outer (A′); front right (B) and aft left inner (B′); front left (C) and aft left outer (C′); front left (D) and aft right inner (D′). Left-right switching and fore-aft beam lobing are caused by coded signals supplied by the receiver-transmitter to the switching modules in the antenna assembly.

The antenna is stabilized in pitch and roll to compensate for changes in aircraft attitude. Pitch and roll stabilization is achieved by means of servo loops which receive pitch and roll attitude signals from a pitch and roll reference input. Servomotors drive the antenna array pitch and roll gimbals through their respective gear trains. The array is also driven in azimuth by a servo loop so it is aligned with the aircraft ground track to compensate for aircraft drift conditions up to 30°. During receive, the return signal is coupled with the antenna through switching modules, through the waveguide assembly to the duplexer, where it is then routed to a receiver switch.

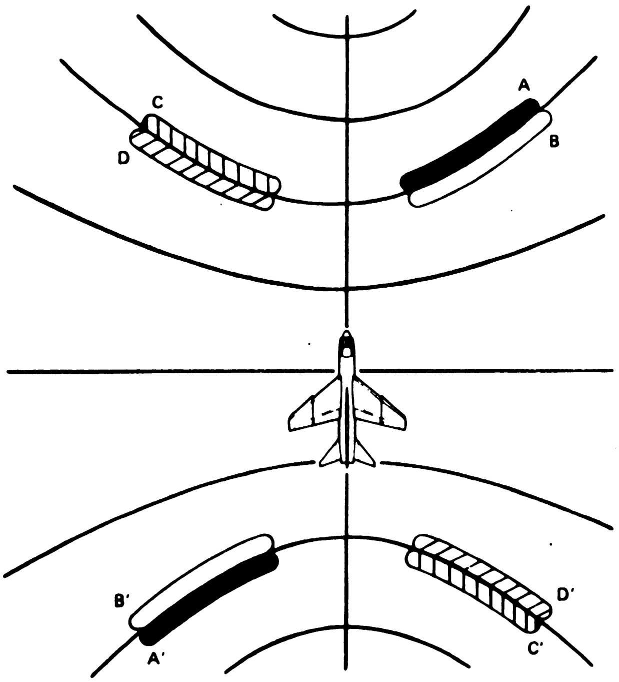


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Figure 9-25.—Antenna radiation pattern.

The receiver accepts the Doppler return and processes it to provide output frequencies falling within a 1- to 36-kHz band, which contains both ground speed and azimuth drift information. These output frequencies are applied to frequency tracking circuits, which consists of ground-speed tracking and azimuth tracking loops. The ground tracking circuits measure Doppler frequency and provide an analog ground-speed output. The azimuth tracking loops compare Doppler shift of two transversely switched beam-pair returns and drive the antenna in azimuth until it is aligned with the ground track, at which time Doppler shifts from both beams are equal. A potentiometer positioned by an antenna azimuth drive shaft provides an electrical analog output of drift angle to analog-to-frequency conversion circuits. Frequency-to-digital conversion circuits using input frequencies representing ground speed and drift angle provide a 60-bit word representing ground speed, drift angle, and system status for use by digital navigation computers and in inertial system correction.

SUMMARY

In this chapter, we have discussed the fundamentals of the inertial navigation systems and the Doppler radar systems used with them.

NAVIGATION—There are two methods of navigation: position fixing and dead reckoning. Position fixing measures a position relative to some known object. Dead reckoning measures speed and heading and, using these measurements, computes the position change from an initial position fix.

INERTIAL NAVIGATION—An inertial navigation system is a dead reckoning system which has very good accuracy. Instead of measuring speed directly, the system derives it from measurements of the vehicle's accelerometers. Two accelerometers are used: one accelerometer is pointed north and the other is pointed east. The first integral with respect to time of these accelerations gives the north and east changes in velocity. The second integral with respect to time gives the north and east position changes. The vehicle's position must be inserted for accurate navigation.

SCHULER TUNING—Schuler tuning is used in most inertial navigation systems. It maintains the stable platform in an orientation perpendicular to the earth's gravity. It also reduces long-term errors, resulting from certain imperfections in the instruments.

DOPPLER RADAR—The Doppler radar employs CW RF transmission in conjunction with the "Doppler effect." The CW Doppler radar senses velocity by measuring a proportional shift in frequency of the reflected signal.

DOPPLER EFFECT—The Doppler effect is the apparent increase or decrease in frequency in a receiver signal resulting from the movement of either the transmitter or receiver, or both relative to each other, or from simultaneous movement of a combined transmitter-receiver relative to a fixed reflecting surface. A general rule in Doppler radar is the more beams used, the more accurate, and simultaneous the information.

CHAPTER 10

ELECTRO-OPTICAL SIGHTS

The purpose of the electro-optical display unit is to display attack and flight information directly to the pilot's field of view. The electro-optical sight uses a light source (fig. 10-1) to display information which is useful to the pilot. In figure 10-2, you can see a modern example of an optical sight. Notice the use of a Cathode-Ray Tube (CRT) to produce the displayed information. This system is known as a Head-Up Display (HUD). In this chapter, you will see how these systems display attack and flight information directly to the pilot's field of view.

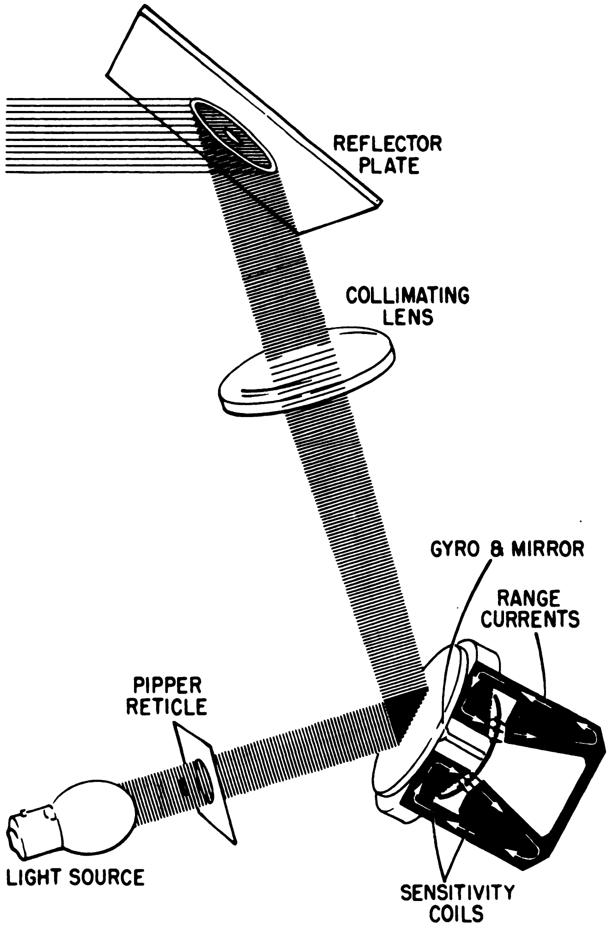

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Figure 10-1.—Basic principle of a sight unit.

The systems you will learn about in this rate training manual are the AN/AVQ-7(V) and the AVA-12. They were chosen for you to study because they represent the systems currently in use. The AN/AVQ-7(V) is used in attack aircraft with a primary air-to-ground mission. The AVA-12 is used in fighter aircraft with a basic air-to-air mission.

AN/AVQ-7(V) HEAD-UP DISPLAY

The AN/AVQ-7(V) receives computed attack and navigation input data from a tactical computer set, aircraft performance data from aircraft flight sensors, and discrete signals from various aircraft systems. Information received from the various systems is displayed on a transparent mirror (combiner) located directly in front of the pilot at eye level. The symbols are focused to infinity and are superimposed over real world objects in line with the aircraft flight path. Certain symbols are positioned on the combiner to correspond with real world object positions relative to the aircraft, even though the real world objects may not be visible.

OPERATION

The head-up display set receives numerous input signals from many aircraft systems and

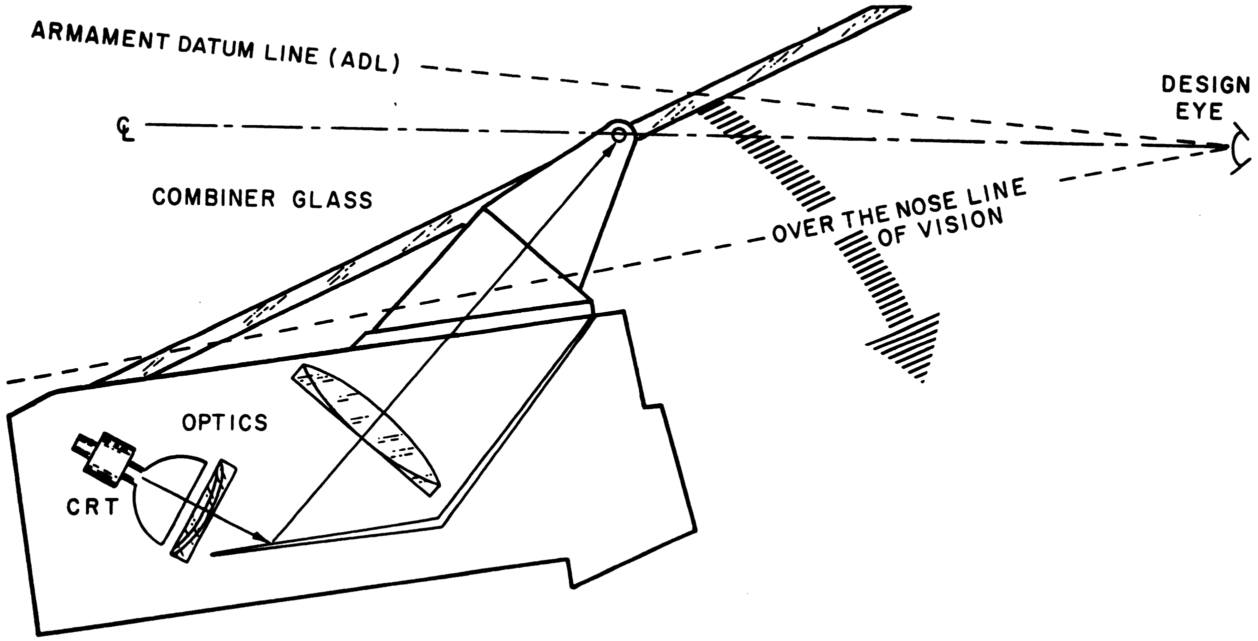
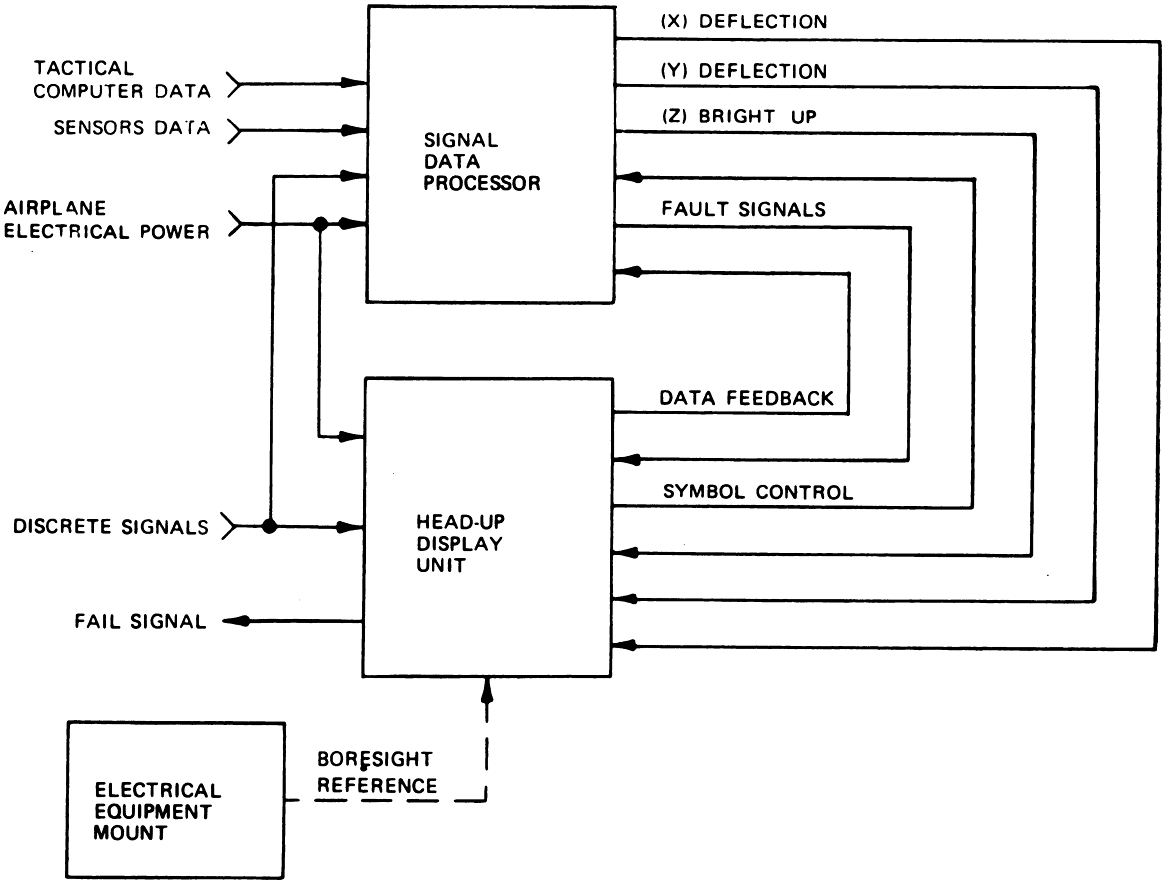


Figure 10-2.—New optical sight with CRT.

sensors (fig. 10-3). The input data is processed by the signal data processor and applied to the HUD as horizontal (X), vertical (Y), and bright-up (Z) signals that provide the symbols which appear on the combiner. All symbols displayed by the HUD are shown in figure 10-4. Self-detected fail signals within the processor or the display unit are transmitted to the tactical computer and caution light panel.

Aircraft ac and dc voltages applied to the power supplies are converted to the required voltage levels and distributed throughout the processor. The precision 15-volt dc power supply output is used for excitation by the angle-of-attack transducer, air data computer, and Doppler radar. Power control of the processor is provided by the display unit. The Built-In Test Equipment (BITE) monitors the power supply voltages and initiates a processor fail signal when an out-of-tolerance condition is detected. The fail signal is not initiated, however, until a Self-Test Command (STC) signal is received from the display unit BITE. Input signals applied to the processor are classified according to three types: discrete (switch closure), analog (variable), and digital (binary quantities). These signals are received by the input receivers within the processor where each signal is identified. Data from the input receivers is checked for validity, parity, and identity by circuits in the processor. When valid, the data is stored in the data store section of the processor. Analog data from the input receivers is applied to the symbol generator, where the analog data is converted to digital form (ADC), and then transferred to the data store until needed by the processor. Each time the Demand-Next Instruction (DNI) pulse is applied to the program store, specific instructions (with decodes) are initiated to the processor. The instructions control the processing of all data contained in the data store. Data is transferred from the data store to the processor where arithmetical functions are performed. The processed data is then returned to the



222.341

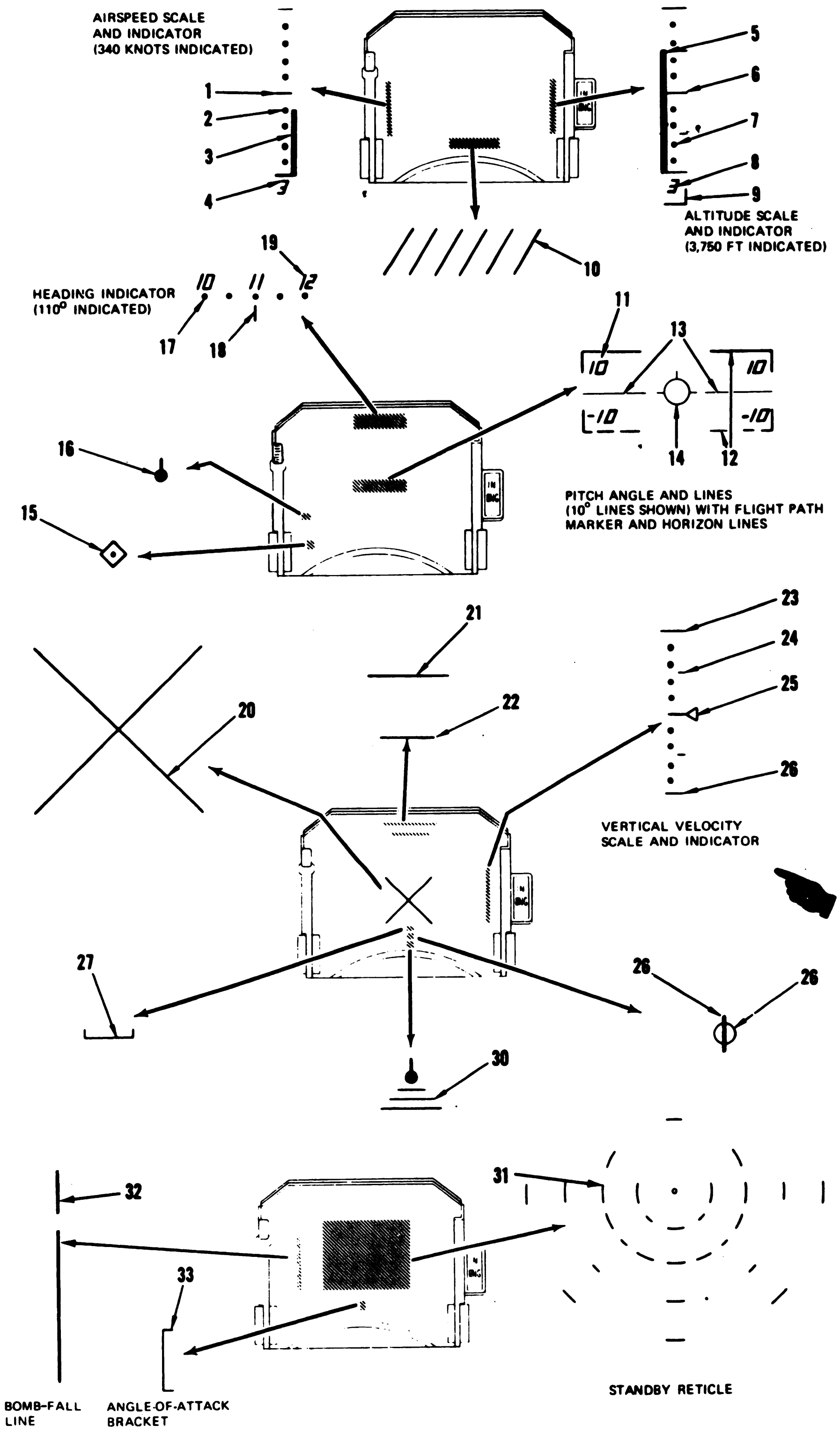
Figure 10-3.—Head-up display set block diagram.

data store. Other instructions transfer processed data (final data) to the symbol generator. The final data controls the generation of X and Y analog voltages used by the display unit. The busy signal prevents the transfer of information to the display unit while it is operating.

The optical module provides power control to the low voltage power supply and symbol control to the processor. Aircraft power is applied to the optical module for control of the standby reticle and complete HUD operation. The BITE circuits, which sense a go/no-go condition in either the processor or the display unit, provide an output to the tactical computer and caution light panel when the HUD is either off or inoperative. If an overheated condition exists, a separate circuit sends a HUD hot signal to the caution panel.

SIGNAL DATA PROCESSOR

Three-phase ac power is applied to six different rectifiers contained in the low voltage power supply. The ac voltage is rectified by each rectifier, then regulated to a precise value. Each value of dc supply voltage is distributed for circuit operation through the signal data processor (fig. 10-5, a foldout at the end of this chapter).


AIRSPEED SCALE AND INDICATOR (340 KNOTS INDICATED)
1
2
3
4
5
6
7
8
9
ALTITUDE SCALE AND INDICATOR (3,750 FT INDICATED)
10
19
HEADING INDICATOR (110° INDICATED)
17
18
11
13
14
12
16
15
PITCH ANGLE AND LINES (10° LINES SHOWN) WITH FLIGHT PATH MARKER AND HORIZON LINES
21
22
20
23
24
25
26
VERTICAL VELOCITY SCALE AND INDICATOR
27
28
29
30
31
32
33
STANDBY RETICLE
BOMB-FALL LINE
ANGLE-OF-ATTACK BRACKET

222.34

Figure 10-4.—Head-up display set displayed symbols.

INDEX NO.	NOMENCLATURE	FUNCTION
1	Index lines	Divides airspeed indicator into 50-knot increments.
2	Index dots	Divides airspeed indicator into 10-knot increments.
3	Airspeed column	Rises on increasing airspeed through increments of 100 knots.
4	Airspeed numeric	Indicates airplane airspeed in increments of 100 knots.
5	Altitude column	Rises on increasing altitude through increments of 1,000 feet.
6	Index lines	Divides altitude indicator into 500-foot increments.
7	Index dots	Divides altitude indicator into 100-foot increments.
8	Altitude numeric	Indicates airplane altitude in increments of 1,000 feet.
9	Radar altitude advisory symbol	Indicates radar altitude is being displayed (altitude switch in RDR ALT)
10	Warning indicator	Flashes when the master caution light goes on. Goes on steady when fire warning light goes on.
11	Pitch angle numeric	Indicates airplane pitch angle. (Scale is times 1°.)
12	Pitch lines	Airplane pitch axis index. (End tabs point in direction of horizon.)
13	Horizon lines	Represents relative position of horizon to the airplane pitch and roll axes.
14	Flight path marker	Represents the flight path of the airplane.
15	Aiming reticle	Enables pilot to locate and track target in attack mode or obtain fix point reference in navigation mode. (Dot in reticle on airplanes after A-7 Airframe Change No. 196.)
16	Flight director	Indicates the relative position of an optimum flight path.
17	Index dots	Divides the airplane heading scale into 5° increments.
18	Lubber line	Indicates airplane magnetic heading.
19	Heading numeric	Airplane heading scale. (Scale is times 10°.)
20	Pull-up command	Flashes on to indicate an immediate pull-up requirement.
21	Solution No. 2 cue	Symbol moves down the bombfall line to indicate an approaching weapons release point.
22	Solution No. 1 cue	Symbol moves down the bombfall line and indicates an approaching weapons release point.
23	Upper index line	Full scale climb index marker. Indicates 1,000 feet per minute climb
24	Index mark	Divides the vertical velocity scale indicator into 500-foot increments.
25	Vertical velocity pointer	Moves up and down scale to indicate vertical velocity.
26	Lower index line	Full scale dive index marker. Indicates 1,000 feet per minute dive.
27	Pull-up anticipation cue	Symbol moves up to indicate an approaching pull-up requirement.
28	Lubber line (Airplanes before A-7 Airframe Change No. 196)	Side slip ball reference line.
29	Side slip ball	Indicates airplane lateral acceleration (side slip).
30	Landing director	Indicates the relative position of the landing flight path during a landing approach.
31	Standby reticle	A manually controlled optical sight used when the head-up display set is inoperative.
32	Bomb-fall line	Indicates weapons delivery path relative to the flight path of the airplane.
33	Angle-of-attack bracket	Moves up and down about the flight path marker to indicate the airplane angle of attack.

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Figure 10-4.—Head-up display set displayed symbols—Continued.

Input Receivers

Digital data signals (table 10-1) are applied to the input receivers on four channels. Data transfer is in serial form and all four channels are in operation at the same time. Each channel consists of a signal and a signal return line. Specific input data is applied to each channel as follows:

1. One channel receives data word signal and data word signal return.
2. One channel receives data identity signal and data identity signal return.
3. One channel receives data ready signal and data ready signal return.
4. One channel receives data clock signal and data clock signal return.

Data identity signals are transmitted simultaneously with each data word signal and identify each data word. Data identity signals consist of 20 bits of data which contain the information shown in table 10-2.

Table 10-1.—Digital data signal

Data Bit	Designation
1	Control bit (binary one)
2	Validity bit (binary one when valid)
3-5	Not used
6-17	Data bits
18	Sign bit (+ equals binary zero)
19	Spare bit (binary zero)
20	Parity bit (odd)
	Digital one is: 0.0 (±0.5) V dc
	Digital zero is: +5.0 (+1.0) V dc

Table 10-2.—Data identity signal

Data Bit	Designation
1	Control bit (binary one)
2-11	Not used
12-18	Data identity (LSB least significant bit first)
19	Spare bit (binary zero)
20	Parity bit (odd)
	Digital one is: 0.0 (+0.5) V dc
	Digital zero is: +5.0 (+1.0) V dc

Data ready is indicated by a digital *one* transmitted concurrently with bit *one* of the data word signal and the leading edge of a data clock pulse. The data clock pulse applied to the input receivers is generated within the tactical computer. The clock pulse has a pulse rate of 50 kHz (+ 10%) with a 50 percent duty cycle. The digital data from the tactical computer is continuously accepted by the input receivers and shifted into the buffer register. Each data word is identified by data identity and clock pulse signals applied to the identity register. At specific intervals in each cycle, accumulated raw data is shifted to the digital computer memory via the adder. Addresses for the raw data are provided by the identity register during the shifting process. There are 12 discrete lines connected to 12 discrete receivers contained in the input receivers. The discrete receivers convert any applied discrete signal to an optimum voltage which is used to control the content of a 12-bit data word. During a digital computer cycle, according to instructions from the program store, a discrete word is read into the function decode. The control terms provided by the discrete word are applied to the digital computer as basic instructions which may or may not affect digital computer operations. Ten analog voltages are divided equally and applied to five

X channel amplifiers and five Y channel amplifiers. Each analog voltage is amplified, then applied to the input selectors. On a gating control command from the symbol generator, one specific analog voltage from each channel is gated to the symbol generator where the Analog-to-Digital Conversion (ADC) is performed.

Digital Computer

Designated letters are used to represent certain phases of digital computer operations. A number following a designated letter indicates a specific step of the phase in progress. The digital computer processes the applied digital data in three phases. After the three phases are completed, the entire cycle is repeated. All steps of each phase are performed sequentially according to a prewired program of instructions contained in the program store. When electrical power is applied to the digital computer, clock pulses are generated within the clock generator of the program store. The clock pulses are distributed by the control logic to the sequence control, input receivers, symbol generator, and processor counter. The processor counter is used to record a specific number of clock pulses so that the DNI pulse is not arbitrarily initiated. However, if a jump signal is received by the function decode, a DNI pulse is initiated. The jump signal may be repeated until the correct instruction is selected. When the DNI pulse is initiated and is in coincidence with a specific clock pulse in the sequence control, a data request signal is applied to the program of instructions.

At the start of digital computer operations, the first program of instructions selected is data accumulation (phase A) due to resetting of the sequence control when electrical power is applied. All instructions of phase A are sequentially applied (as step A1) to the processor function decode. The function decode determines the addresses of all the instructions received and applies this information to the memory. The phase A instructions are decoded by the function decode and applied as read-in commands (as step A2) to the adder. All data accumulated in the buffer register is transferred (as step A3) via the adder (as step A4) to the memory, which completes phase A of digital computer operations. The function decode is then ready for the specific clock pulse from the counter that initiates the DNI pulse to the sequence control.

When the next DNI pulse is received by the sequence control, a request for the next sequence of instructions (phase B) is applied to the program of instructions. All instructions contained in the next program are sequentially transferred (as step B1) to the function decode. The phase B instructions are decoded by the function decode and all addresses contained in the instructions are applied to the memory. The decoded phase B instructions are commands to transfer certain data (as step B2) contained in the memory to the adder. Other phase B instructions command arithmetical functions to be performed (as step B3) by the adder. As soon as solutions are obtained, they are transferred (as step B4) to the memory. Phase B of computer operations is then complete. The sequence control is then ready for the next DNI pulse from the function decode.

The next DNI pulse starts phase C of the digital computer operations. Selection of phase C instructions is initiated to the program of instructions. The next sequence of operations is the application of coded instructions (as step C1) to the function decode. The phase C instructions are decoded by the function decode and all addresses contained in the instructions are applied to the memory. The decoded phase C instructions are commands to transfer the processed data (as step C2) via the adder (as step C3) to the symbol generator which completes the three-phase cycle. On the next DNI pulse, the entire process is repeated. This cycle continues until electrical power is removed from the digital computer.

Symbol Generator

The symbol generator operates in three major modes. The three modes of operation are the line, circle, and analog-to-digital conversion (ADC). Each mode is independently and completely performed before repeating or starting a different mode. The mode to be performed is initiated by the function decode in the digital computer. Correct sequencing of each mode of operation is provided by the timing pulses from the control logic section of the digital computer. The program in the digital computer determines which mode is initiated to the symbol generator.

LINE MODE.—When a line is to be drawn in the CRT, a line mode signal is initiated to the input/output buffer and control of the symbol generator. This signal starts a counter that controls all operations of the symbol generator. The first operation is to transfer the X1 data from the memory through the adder and input/output buffer and control to the X channel deflection register. The X1 data is the digital equivalent of the analog voltage used to drive the electron beam to the start point (in the horizontal axis) of the line to be drawn. The second operation is to transfer the Y1 data from the memory to the Y channel deflection register. The Y1 data is the digital equivalent of the analog voltage used to drive the electron beam to the start point (in the vertical axis) of the line to be drawn. The digital data contained in each deflection register is immediately converted to an equivalent analog voltage by the X and Y channel Digital-to-Analog Converters (DAC). This analog voltage (X and Y deflection voltage) is held by each DAC until gated to the HUD by the input/output buffer and control. The third operation is to transfer the X2 data from the memory to the parameter register. The X2 data is a digital quantity representing the line slope angle cosine. In the first half of the fourth operation, the X2 data is shifted from the parameter register to the X channel rate register. In the second half of the fourth operation, Y2 data is transferred from the memory to the parameter register. The Y2 data is a digital quantity representing the line slope angle sine. In the first half of the fifth operation, the Y2 data is shifted from the parameter register to the Y channel rate register. In the second half of the fifth operation, the T data is transferred from the memory to the parameter register. The T data is a digital quantity representing the length of the line to be drawn (bright-up pulse width). In the sixth and seventh operations, all data contained in the X and Y channel rate registers are checked for correctness by the BITE circuits. All the data required to draw a specific line (which may be only part of a symbol) is now contained in the symbol generator.

When all the data required to draw a specific line is contained in the symbol generator, the busy signal from the HUD is sampled. If the busy signal is high, the operations stop until the busy signal is low. When the busy signal goes low, the input/output buffer and control sends a start pulse to the parameter register which causes it to start down counting. The down counting controls the length of time the bright-up pulse is applied to the HUD. At the same instant, a gating pulse is applied to each DAC. This allows an analog voltage (produced by the digital content of each deflection register) to be applied to the deflection circuits in the HUD. Also, at the same instant, the contents of the rate registers are added to or subtracted from the respective residue register which causes a positive or negative overflow to be generated. The overflow is used to drive the deflection registers up or down. This causes the start point of the line to move in the direction of the line slope angle. After a preset time delay, a bright-up pulse is applied to the HUD. The time delay will compensate for the slower response time of the deflection circuits in the HUD. The bright-up pulse continues until the parameter register has down counted to zero. When the parameter register stops counting, the bright-up pulse is turned off, and the end of the line mode is indicated to the digital computer. The line mode may be repeated as many times as necessary to complete the required symbol.

CIRCLE MODE.—When a circle is to be drawn on the CRT, a circle mode signal is initiated to the input/output buffer and control. This signal starts the operation counter as in the line mode. The data required to draw a circle, in a specific location, is transferred to the symbol generator in the same manner as in the line mode. However, the X2 data is equal to negative one and the Y2 data is all zeros. The T data set into the parameter register is the digital equivalent of one over the circle radius. Circles are drawn in a counterclockwise direction starting from the top. The overflow from the residue registers control the direction and amount of change in each deflection register. However, in the circle mode, the overflow also controls the circle logic to the opposite channel. The circle logic is such that a positive X channel overflow causes the contents of the parameter register to be added to the contents of the Y channel rate register. If the X channel overflow is negative, then the contents of the parameter register are subtracted from the Y channel rate register. On the other hand, if the overflow from the Y channel residue register is positive, then the contents of the parameter register are subtracted from the X channel rate register. If the Y channel overflow is negative, then the contents of the parameter register are added to the X channel rate register. This cross-coupling causes the two channels to be interdependent on each other. As the rate of change in one channel increases, the rate of change in the other channel decreases, or vice versa. If the circle being drawn is large, the rate of change in the analog deflection voltage output is large. If the circle is small, the rate of change in the analog deflection voltage is small. The rate of change is inversely proportional to the contents of the parameter register which contains the inverse of the circle radius. Thus, a circle with the desired radius is produced. The bright-up pulse is controlled by a quadrant counter in the input/output buffer and a control which turns on the bright-up pulse after the electron beam has traversed halfway around the circle. The bright-up pulse delay compensates for the slow response time of the deflection circuits in the HUD. The bright-up pulse stays on until the quadrant counter has counted four times. A short time after the fourth count, the bright-up pulse is turned off and the symbol generator busy signal is terminated. This completes the circle mode.

ANALOG-TO-DIGITAL CONVERSION (ADC) MODE.—The third and final mode of symbol generator operation is the analog-to-digital conversion (ADC) mode. In this mode, the operation of both (X and Y) channels is identical. Therefore, only the X channel operation is described. At the start of the ADC mode, the most significant bit in the parameter register is set to the one level. The rate and deflection registers are set to zero and coupled directly to each other. The direct coupling of the two registers is provided so the contents of either register will be duplicated. The third step gates a specific analog voltage from the X channel input selector to one side of the X channel comparator. The fourth step gates the digital-to-analog converter (DAC) voltage from the X channel DAC to the other side of the X channel comparator. The DAC voltage represents the contents of the X channel deflection register (and rate register due to coupling). If a difference in voltage level exists between the two applied voltages, the comparator has an output applied to the deflection register. The output of the comparator represents the sine of the difference and causes the contents of the parameter register to be added to or subtracted from the contents of the rate register. On the next operation, the one in the parameter register is shifted to the next lower bit location and the voltage comparison phase repeated. This process is continued until the parameter register reaches zero. When the parameter register reaches zero, the contents in the rate register (in digital form) are equal to the input selectors analog voltage applied to the comparator. The next operation transfers the contents of the rate register to the memory by way of the data feedback (DFB) lines. In subsequent operations, the remaining analog voltages are applied to the comparator and the entire process repeated. The ADC mode continues until all analog voltages are converted to digital data and stored in the memory.

HEAD-UP DISPLAY

Aircraft dc power applied to the control panel in the optical module is used for operational control of the signal data processor, head-up

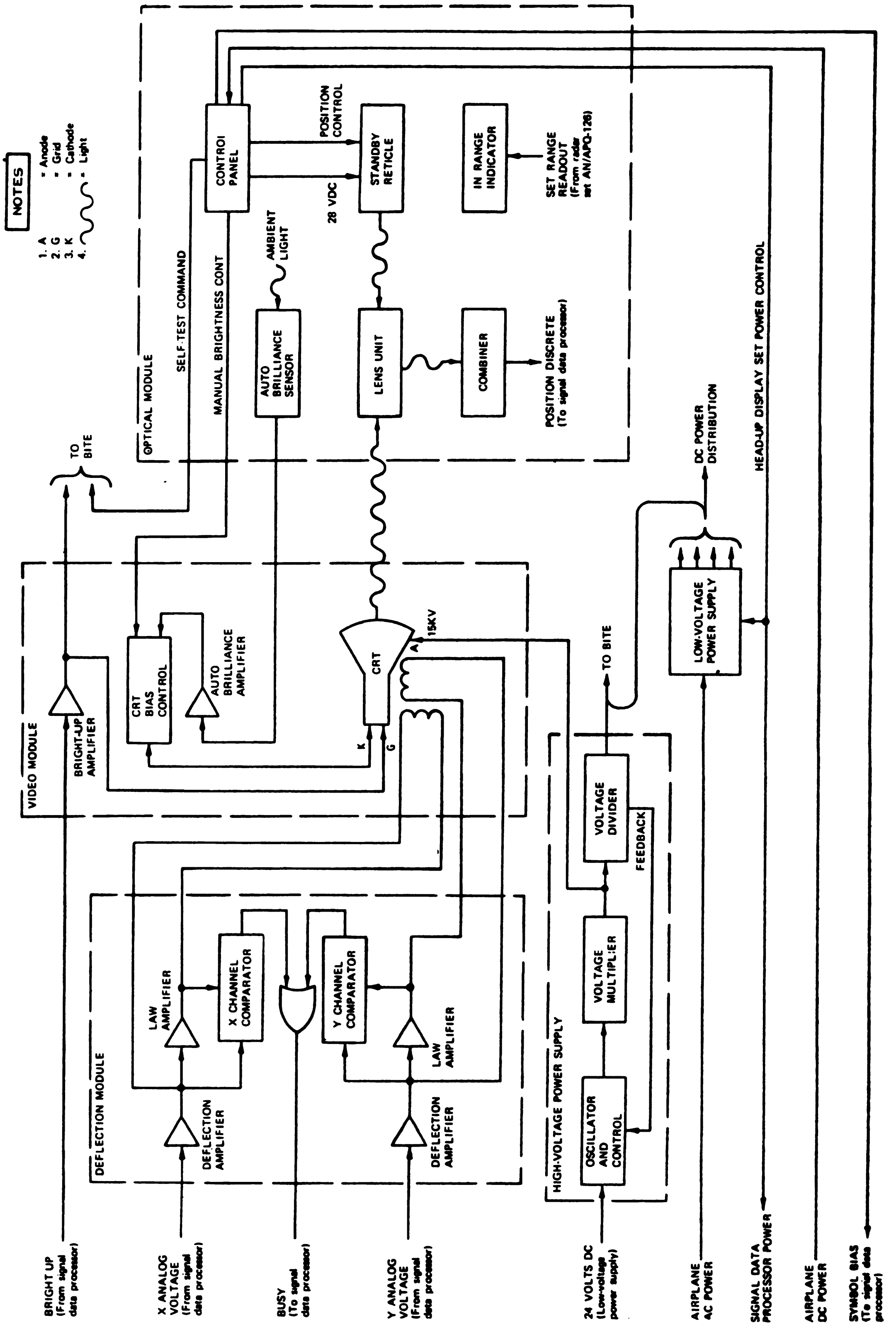

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Figure 10-6.—Head-up display unit signal flow diagram.

display unit, and standby reticle (fig. 10-6). Aircraft ac power applied to the low voltage power supply is rectified, then divided into seven different dc levels for distribution throughout the HUD. A transistorized oscillator to the high voltage power supply receives 24 volts dc excitation from the low voltage power supply. The oscillator output is applied to a voltage multiplier and rectifier circuit that increases the input voltage to 15,000 volts. The 15,000 volts is applied to a CRT anode and a voltage divider within the high voltage power supply. Outputs from the voltage divider are used to control the oscillator frequency and a comparator output. The comparator senses if differences exist between the voltage divider output and a fixed reference voltage. If the high voltage drops below a prescribed level, a fail signal is generated by the comparator and applied to the BITE circuit.

Optical Module

The optical module contains the standby reticle, in-range indicator, control panel autobrilliance sensor, and lens unit. The standby reticle is used only when the HUD is inoperative, and is controlled electrically and mechanically from the control panel. Electrical power used for operation of the standby reticle is obtained from outside the HUD.

Light emitted from the standby reticle is transmitted through the lens unit to the combiner. The in-range indicator indicates when a range discrete signal is received from the forward looking radar set. Symbols are represented by light emitted from a CRT located in the video module. As symbols are drawn on the CRT face, the emitted light is received by the lens unit and applied to the combiner. The desired level of brightness is selected from the control panel by adjustment of the voltage level applied to the cathode bias circuit. The autobrilliance sensor is used to detect ambient light changes. Any change in ambient light proportionally changes the output voltage level of the autobrilliance sensor.

Video Module

The video module contains the bright-up and autobrilliance amplifiers, cathode bias circuit, horizontal and vertical deflection coils, and CRT. Symbols are drawn at the rate of 50 times a second on the CRT. The rapidly moving electron beam is generated by the bright-up pulse from the signal data processor. The bright-up pulse is amplified by the bright-up amplifier then applied to the CRT grid. The CRT, which is normally biased into cutoff, is turned on and an electron beam is emitted. The electron beam strikes the CRT face at a position determined by the amount of current flowing in the horizontal and vertical deflection coils. The amount of light (symbol brightness) emitted from the CRT is controlled by the cathode bias circuit. A control voltage from the control panel is applied to the cathode bias circuit which serves as a reference voltage for the autobrilliance sensor and the CRT cathode. The voltage output from the autobrilliance sensor is amplified by the autobrilliance amplifier. The output is applied to the cathode bias circuit which changes the amount of bias (brightness) on the CRT. This, an optimum CRT contrast, is constantly maintained under varying ambient light.

Deflection Module

The deflection module contains the X and Y deflection amplifiers, X and Y law amplifiers, X and Y comparators, and one OR gate. The type and location of each symbol on the combiner is determined by X and Y analog voltages applied to the deflection circuits. As the need for a symbol arises, the busy signal from the HUD is sampled by the symbol generator. The busy signal is generated any time current is flowing in either deflection coil. Comparators, connected across each coil, are used to detect when the deflection coil current is equal to zero. As the current in either deflection coil reaches zero, the output from the comparator, connected across the coil, goes low. When both comparator outputs are low, the OR gate output goes low and the busy signal is removed from the symbol generator input. At the same instant, the symbol generator applies a precise analog voltage to the X and Y deflection amplifiers. The output from the deflection amplifiers causes current to flow in the deflection coils. The current amplitude is precalculated to drive the CRT electron beam to the start point of the symbol to be drawn. A bright-up pulse is then applied to the bright-up amplifier in the video module. At the same instant, the deflection voltage is modulated at a predetermined rate and amplitude by the symbol generator. The modulation is detected by the deflection amplifiers and applied to each deflection coil. A specific part (or all) of a symbol is then drawn on the CRT face in a precise location. The bright-up pulse continues long enough to draw the prescribed line or circle that makes up the symbol. When the bright-up pulse is removed, the CRT is driven into cutoff until the next bright-up pulse is applied. This process is repeated until all symbols have been displayed on the CRT.

BUILT-IN TEST EQUIPMENT (BITE)

The built-in test equipment (fig. 10-7) contained in the signal data processor (SDP) consists of a clock pulse monitor, data test equipment, raw data test equipment, six low voltage comparators, signal data processor fail indicator, and thermal overload sensor. The AND and OR gates represent various circuit functions of the built-in test equipment. The thermal overload sensor produces an output when the temperature inside the signal data processor rises above an operational limit. The overheat signal is applied to the HUD BITE circuit for subsequent transfer to the caution light panel. The clock pulse monitor checks the frequency of the clock generated in the digital computer section. When an out-of-tolerance condition is detected, a fail signal is applied to OR gate one (OG-1) from the clock pulse monitor. The data test equipment provides two types of data checks. One check consists of comparing the data from each memory location (except raw data locations) to known reference data. If an error is detected, a fail signal is applied to OG-1. The other check consists of comparing the data content, set into the symbol generator, with the original data content in the memory. If an error is detected, a fail signal is applied to OG-1. The data clock, data word, and data identity signals from the input receivers are applied to the raw data test equipment where the validity and identity checks are performed. If an error is detected in the raw data, a fail signal is applied to OG-1 and the input receivers. The fail signal applied to the input receivers is an inhibit signal that prevents the invalid data from being transferred to the digital computer memory. The six low voltage comparators are used to compare a specific voltage from the low voltage power supply with a fixed reference voltage. If the voltage from the low voltage power supply decreases below the fixed reference voltage (within a given percent), a fail signal will be generated by the comparator and applied to OG-1. The output of OG-1 is at high whenever a fail signal has been detected on any one of its nine input lines. The output line of OG-1 is connected to AND gate one (AG-1), AG-2, and the HUD unit BITE circuit. When the inhibit line of AG-1 is high, the output of AG-1 remains low even though a deflection monitor fail signal is present. This prevents the generation of a false deflection monitor fail signal due to a defective signal data processor. The level of the output line of AG-2 is dependent upon the level of its input lines from OG-1 and the HUD unit BITE circuit. When both input lines of AG-2 are high, a fail signal is applied to the SDP fail indicator. The SDP fail indicator is an electromechanical device that must be manually reset once it has been electrically activated.

HEAD-UP DISPLAY UNIT

The built-in test equipment (BITE) contained in the HUD unit consists of a high voltage comparator, seven low voltage comparators, a bright-up parity circuit, a HUD fail indicator, and a thermal overload sensor. The AND and OR gates represent various circuit functions of the BITE. The thermal overload sensor provides the same function as the thermal overload sensor contained in the signal data processor. Both sensor output lines are connected to the input of OG-2. If the output of either sensor is high, an overheat signal from OG-2 is applied to the caution light panel. The signal data processor BITE circuit has two other output lines connected to the HUD BITE circuit. One is the deflection monitor fail, which is one of three input lines to OG-5. The other is the signal data processor fail line, which is one of two input lines to OG-6. When either of the input lines of OG-6 is high, a fail signal from OG-6 is applied to the caution light panel and tactical computer. The fail signal indicates that the HUD has failed. When the deflection monitor fail line goes high, the output of OG-5 goes high. The output line of OG-5 is connected to one of the input lines on both AG-7 and OG-6. The bright-up signal input line is connected to one input of AG-3. The bright-up signal complement line is connected to one input of AG-5, the

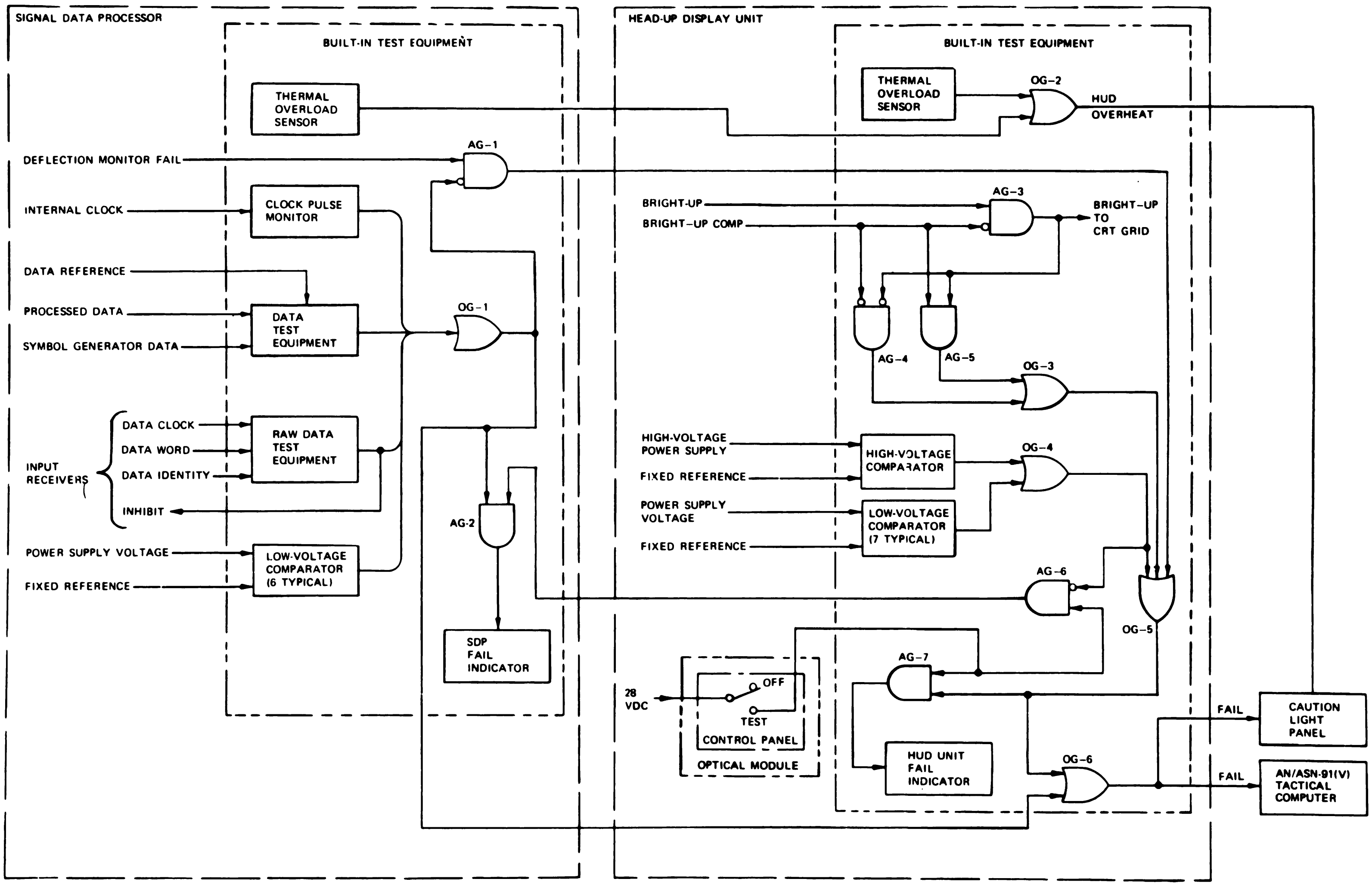

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Figure 10-7.—Built-in test equipment signal flow diagram.

inhibited input of AG-3, and one of the inhibited inputs of AG-4. When the bright-up input line is high and the bright-up complement line is low, a bright-up pulse is applied to the CRT grid. The bright-up pulse is also applied to the other input of AG-5 and the other inhibited input of AG-4. As long as the bright-up complement line is low and the output line of AG-3 is high (or vice versa), there will be no high level output from AG-4 or AG-5. But, if both the bright-up complement and the AG-3 output lines are low at the same time, the output of AG-4 will go high. Also, if both the bright-up complement and the AG-3 output lines are high at the same time, the output of AG-5 goes high. The outputs of AG-4 and AG-5 provide the inputs of OG-3. Thus, if the output of either AG-4 or AG-5 is high, a bright-up parity fail signal is applied to input of OG-5 from OG-3. The high voltage comparator is used to compare a known voltage from the high voltage power supply with a fixed reference voltage. If the known voltage drops below a specified level, the comparator generates a fail signal to OG-4. The seven low voltage comparators are used to compare a specific voltage from the low voltage power supply with a fixed reference voltage. If the voltage from the low voltage power supply should decrease below the fixed reference voltage (within a given percent), a fail signal is generated by the comparator and applied to OG-4. The output of OG-4 is high whenever a fail signal is detected on any one of eight input lines. The output of OG-4 is connected to the input of OG-5 and the inhibited input of AG-6. The other input of AG-6 and AG-7 is connected to the self-test switch on the control panel. The output of AG-5 is

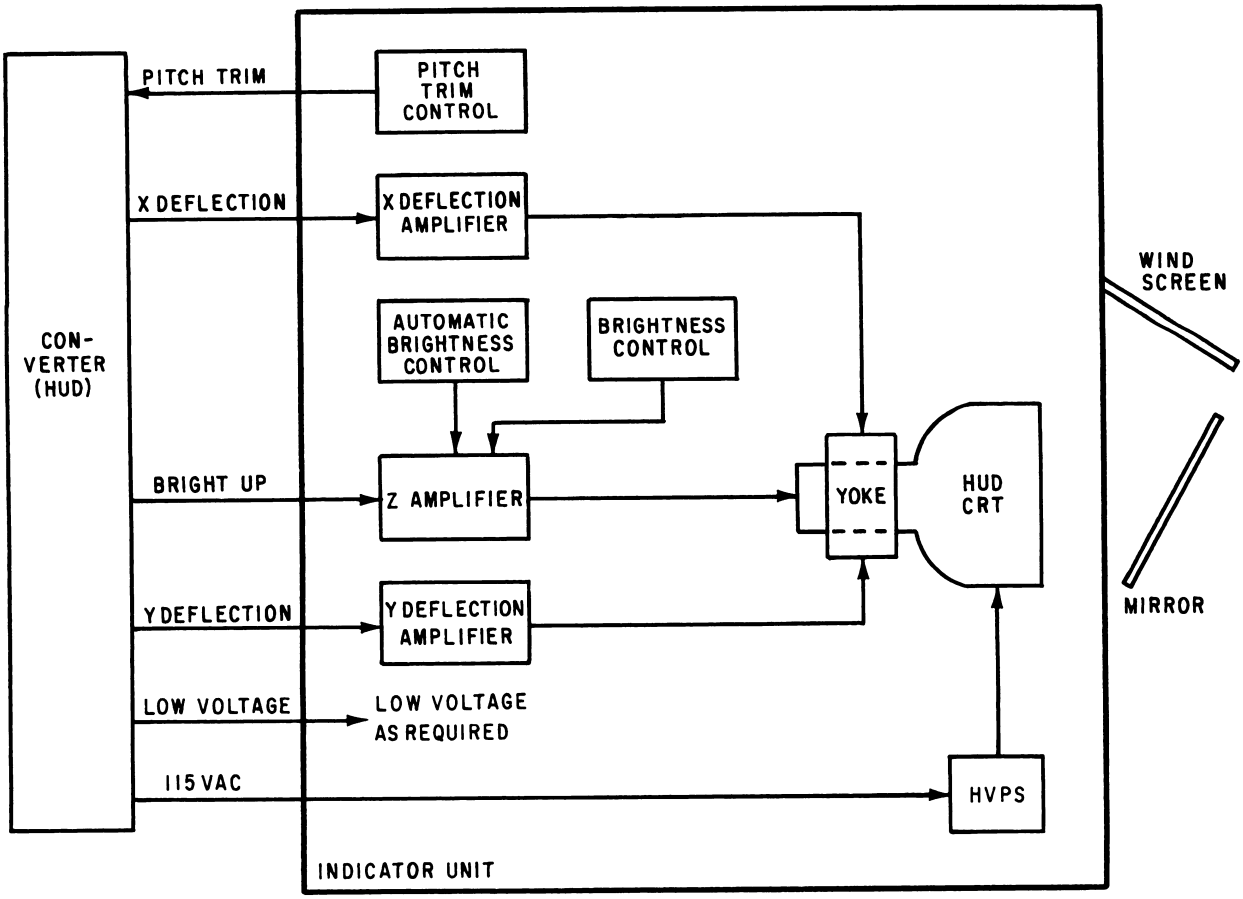

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Figure 10-8.—Head-up display indicator block.

connected to the signal data processor BITE circuit. The output line of AG-6 is high whenever the self-test command (28 volts dc) is applied to one input of AG-6 and the output line from OG-4 is low. However, if the output line from OG-4 is high, the output of AG-6 remains low. This prevents a defective HUD power supply from generating a false signal data processor fail signal. The output line of AG-7 is high whenever the self-test command signal is applied to one of its input lines, and the output line of OG-5 is high. The output of AG-7 is the HUD fail signal which is connected to the HUD unit fail indicator. The HUD unit fail indicator must be manually reset once it has been electrically activated.

AVA-12

The basic operation of the AVA-12 head-up display (HUD) is like that of the AN/AVQ-7(V). The symbols of the two HUDs are generated in the same way. The basic differences between the two systems are the types of symbols which are generated, their use, and the type of aircraft on which the systems are used. The AVA-12 is used on fighter aircraft with a basic air-to-air mission.

Look at the block diagram of the AVA-12 which is shown in figure 10-8. As you can see, the indicator unit receives the deflection and voltage symbols from the converter. Now, look at the converter shown in figure 10-9. The converter takes the aircraft system information and converts it into information which is usable by the display unit.

SYMBOLOGY

The symbols which are used with the various modes of operation on the AVA-12 are listed and described in figure 10-10. These symbols give the pilot important information such as aircraft

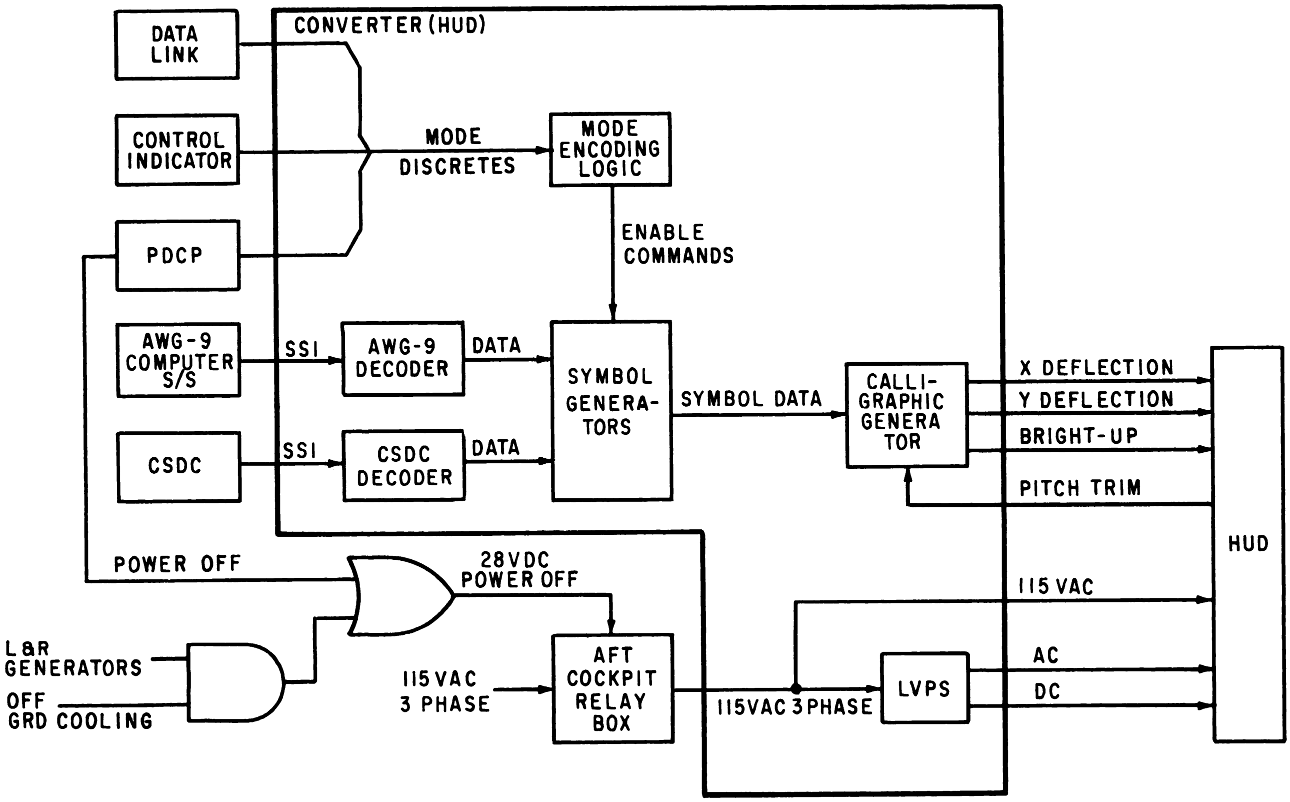

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Figure 10-9.—HUD converter block.

SYMBOLOGY

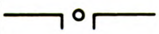
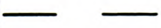
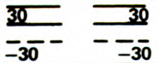
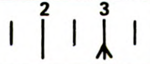
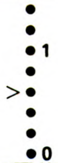
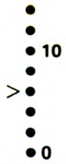
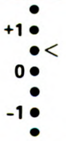
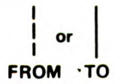
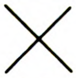
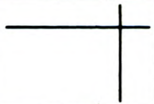
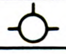
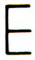
HUD SYMBOL	NAME	FUNCTION
	Aircraft reticle	Depicts own aircraft wings and when lined up with the horizon, the aircraft is in straight and level flight.
	Horizon	This is a demarcation point between ground and sky textures on the VDI. It represents the horizon with respect to the aircraft, and changes orientation with any change in aircraft pitch or roll.
	Pitch lines	Indicates with respect to aircraft reticle pitch attitude. In cruise and A/A mode, HUD pitch lines have a 4:1 compression ratio. Dotted lines indicate a negative pitch. Solid lines indicate positive pitch. Pitch lines above the magnetic heading scale are blanked.
	Magnetic heading (AHRS or WCS via CSDC)	Indicates magnetic heading with respect to index mark.
	Radar Altimter Scale	Indicates altitude derived from radar altimeter. Scale is from 0 to 1400 feet in 200-foot increments and has a movable pointer. This symbol is only available in the takeoff and landing modes.
	Barometric Altimeter Scale	Indicates altitude derived from the pressure altitude via the CADC. Scale is from 0 to 14,000 feet in 2000-foot increments. This scale is available in A/G and TARPS modes. The altitude is referenced to 29.92 inches Hg.
	Vertical Speed Indicator	Indicates rate of altitude change. Scale is from -1500 to +1500 ft/min in 500-foot increments. This scale appears on the left side of the HUD in takeoff and landing modes.
	TACAN Deviation Bar (TACAN via CSDC)	Indicates difference between bearing to TACAN and selected TACAN radial. Deviation is limited to ±5.625° TACAN deviation on the VDI, and ±3° TACAN deviation on the HUD. The symbol never leaves field of view. It will limit at edge nearest selected TACAN radial.
	Breakaway	Appears as a flashing symbol at a 3-cycle per second rate in the center of field-of-view when range-to-go-to minimum or safe pullup point is zero. Symbol is commanded by the WCS computer or by D/L, depending on mode of operation.
	Precision course Vector	This symbol consists of two independent vectors (vertical and horizontal), which form a cross pointer. Elevation glide slope information positions the horizontal vectors, whereas the vertical vector is positioned by azimuth glide slope information. This symbol is also used in D/L bombing modes.
	Velocity Vector	Indicates direction of ground track velocity vector (where the aircraft is going, not where it's pointed).
	Angle of attack error (CADC via CSDC)	Its position in relation to aircraft reticle indicates angle-of-attack error. Symbol is position by true AOA. Small center horizontal bar indicates zero error. When this symbol is in line with the aircraft reticle, the AOA is 15 units (10.31°). If symbol is below aircraft reticle, AOA is too high; above the aircraft reticle indicates AOA is too low. Symbol is displayed in landing mode only.
ORD, G, SW, SP, or PH 0,1,2,3,4,5,6	Armament Ready Legends	ORD – indicates bombs or rockets selected, or bombs and gun selected (A/G GUN switch on ACP set to MIXED) G 6 – indicates gun is selected or gun and bombs are selected (A/G GUN switch on ACP set to OFF). Number under G indicates rounds remaining in hundreds (6, 5, 4, 3, 2, 1, 0). SW, SP or PH – indicates missile type selected (Sidewinder, Sparrow or Phoenix) and the numbers (0 to 6) indicates number of missiles ready for launch.

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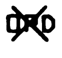
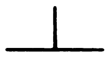
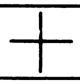
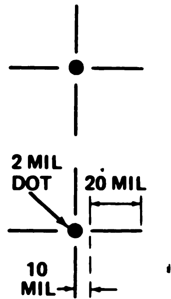
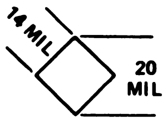
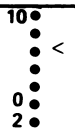
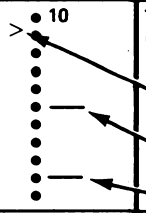
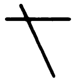
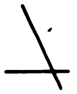
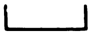
Figure 10-10(A).—Symbology.

HUD SYMBOL	NAME	FUNCTION
	MASTER ARM switch off	An X symbol through armament ready legend indicates MASTER ARM switch on ACM panel is OFF. Disappears when MASTER ARM switch is set to ON.
	Steering Tee	Provides elevation and azimuth steering in the air-to-air modes when a single target track exists. Type of steering (pursuit, collision, etc.) is dependent on weapon selection and the mode selected on the TID by the RIO. May also provide azimuth steering only on the VDI in TWS. Aircraft steering is accomplished by aligning and maintaining the vertical and horizontal bar of the inverted T with the aircraft reticle center dot. Steering sensitivity on the HUD is 26.5° per inch; on the VDI 25° per inch.
	Boresight Reference	Symbol is a set of crosshairs which is fixed on the HUD and is used to represent the armament data line (ADL) of the aircraft. The reference is located 5.03° above aircraft reticle.
	Moveable Reticle (Impact Point)	Symbol serves as an optical sight for A/A gunnery and for A/G weapons delivery. In A/A gunnery, the symbol is used for lead angle determination. It can be positioned manually using the elevation lead control or automatically by the computer when the pilot selects the gun solution mode. The symbol is so designed that stadiametric ranging techniques can be employed during manual gun firing mode. This symbol in A/G modes indicates instantaneous weapon impact point. This symbol is positioned by the computer in all modes except manual. In the manual mode, it is positioned by the elevation lead control. The computer positions the symbol based on the ballistics of the bomb, wind conditions, and various aircraft parameters. This symbol must overlay the target at the moment of release.
	Target Designator	Indicates redar pointing angle. This symbol is used in all computer A/G modes. It is positioned in this case by the pilot using the TARGET DESIGNATE switch. Once the symbol is over the target, the switch is depressed and the computer knows the slant range to the target. In real-time gunsight mode of air-to-air gun, the target designator is positioned at the 1000-foot bullet solution. In all other weapon modes or with OFF selected, and with a valid sensor angle track on the target, the target designator symbol represents the approximate line of sight to the target. If the target is not within the HUD field of view (FOV) the symbol is positioned at the edge of the FOV in the direction of the target. Limits of designator are 10° in horizontal and vertical.
	Closure Rate	Indicates closing velocity from -200 to +1000 knots between aircraft and target.
	Target Range Scale (azimuth range bar) Target Range Mark Maximum Range Mark Minimum Range Mark	Appears on right side of HUD during A/A modes. Scaling is determined by RIO selecting RANGE pushbuttons on the DDD panel. On the VDI, the range scaling is indicated in the lower left corner of the display. Limits are ±35° in horizontal. The symbol appears on the left side of the VDI during A/A modes, except in STT when it will be located at target azimuth. Indicates range to target. Indicates maximum range for weapon launch. Indicates minimum range for weapon launch.
	Upper Solution Cue	Cue is a measure of instantaneous weapon range. It is constrained to motion on the bomb fall line. Displayed with respect to velocity vector to indicate range-to-go to weapon release. When it crosses the velocity vector symbol the computer commands a weapon release.
	Lower Solution Cue	Cue is a measure of maximum range of weapon calculated from instantaneous aircraft position, constrained to motion on the bomb fall line and is used in conjunction with velocity vector to indicate range-to-go-to in range. In range when cue crosses velocity vector and indicates weapon can reach target if pilot executes a pullup. Cue appears after designate.
	Pullup Cue	Cue is a measure of range at which a 4 g pullup is required to clear weapon fragmentation pattern or ground. Positioned directly below velocity vector. Used in conjunction with velocity vector to indicate range-to-go to minimum safe pullup point, when one crosses the other.

222.553

Figure 10-10(B).—Symbology—Continued.

attitude, heading, altitude, angle of attack, and ground track during flight. Attack information including closure rate, range to target, maximum range for weapon launch, minimum range for weapon launch, and boresight reference is available during air-to-air and air-to-ground operations. Ordnance information available includes number of rounds remaining, the type of weapon selected, and the number of weapons ready for launch.

DECLUTTER

The AVA-12 has a feature known as declutter. It is used to remove preselected unwanted symbols from the display during certain modes of operation. This information is especially important during an air-to-air or "dogfight" situation. It removes unwanted symbols from the pilot's field of view when trying to locate and engage an enemy target.

DISPLAY MODES

The AVA-12 has five basic modes of operation. These modes are takeoff, cruise, air-to-air (A/A), air-to-ground (A/G), and landing.

Takeoff

The takeoff mode is shown in figure 10-11. This mode is used during takeoff and displays vertical speed, altitude, and aircraft attitude.

Cruise

The cruise mode is shown in figure 10-12. This display is used primarily for flight from one point to another. The display gives the pilot attitude reference, magnetic heading, and various weapon information.

Air-to-air

The air-to-air mode is shown in figures 10-13 through 10-16. These displays give the pilot attack data with the various types of air-to-air weapons selected. In addition to attitude reference, the weapon type and number of weapons on board are displayed along with various types of target information.

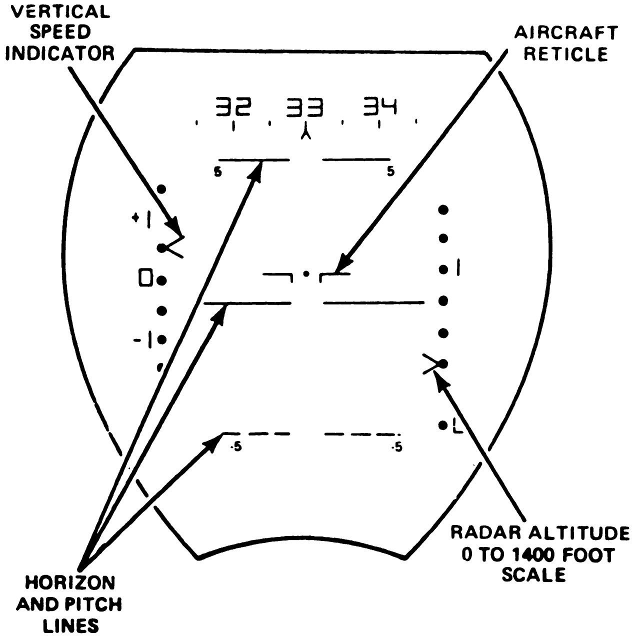


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Figure 10-11.—Takeoff mode.

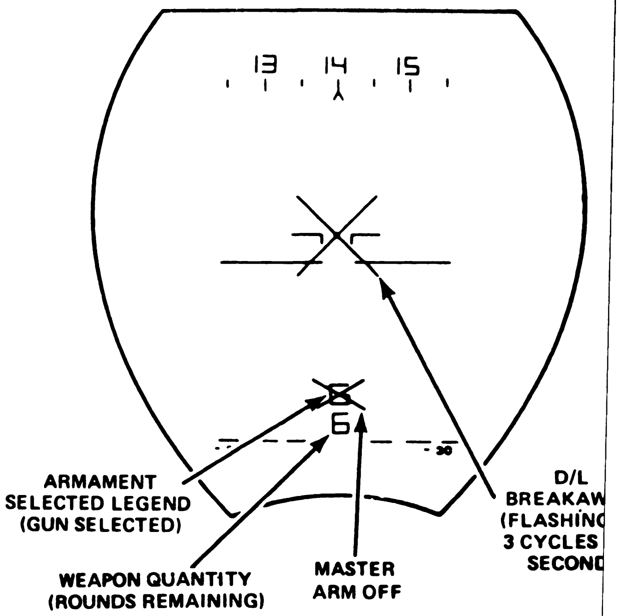
13
14
15
6
30
ARMAMENT SELECTED LEGEND (GUN SELECTED)
WEAPON QUANTITY (ROUNDS REMAINING)
MASTER ARM OFF
D/L BREAKAW (FLASHIN 3 CYCLES SECON

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Figure 10-12.—Cruise mode.

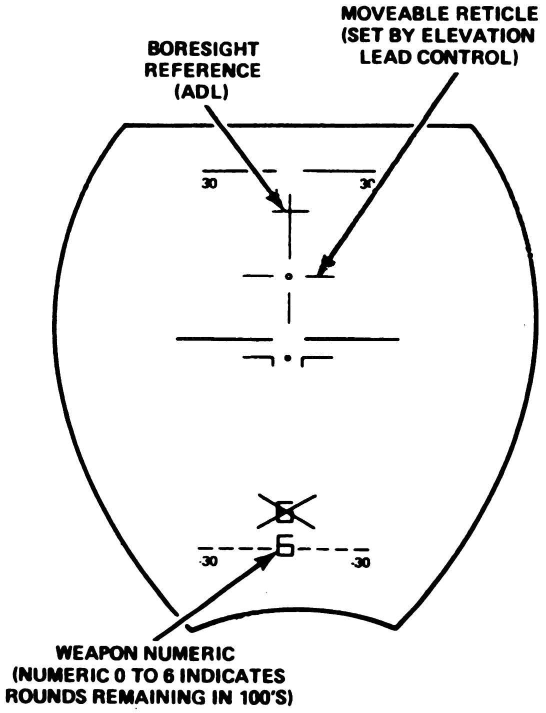

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Figure 10-13.—Gun mode.

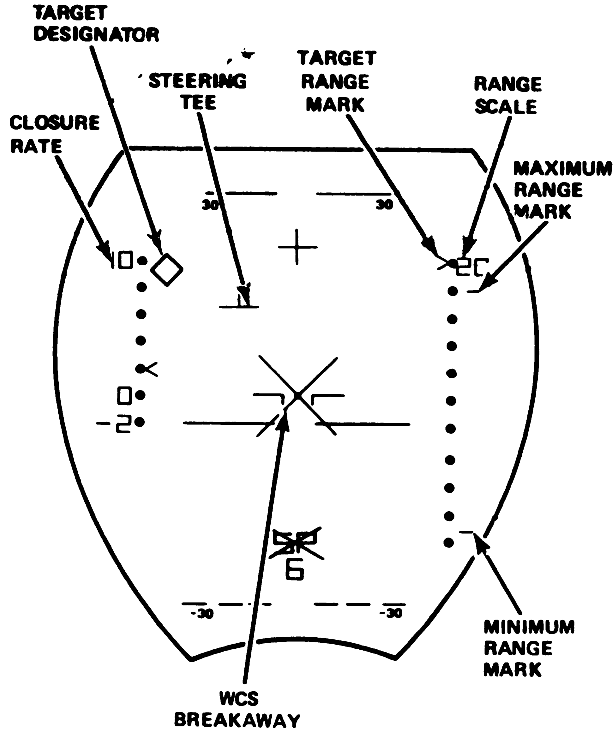

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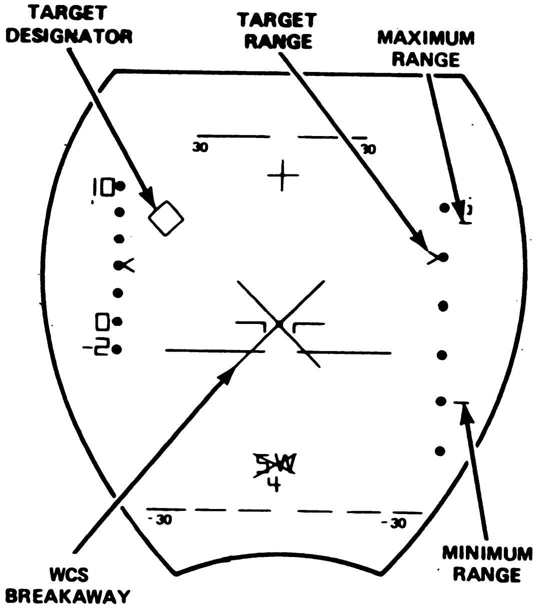
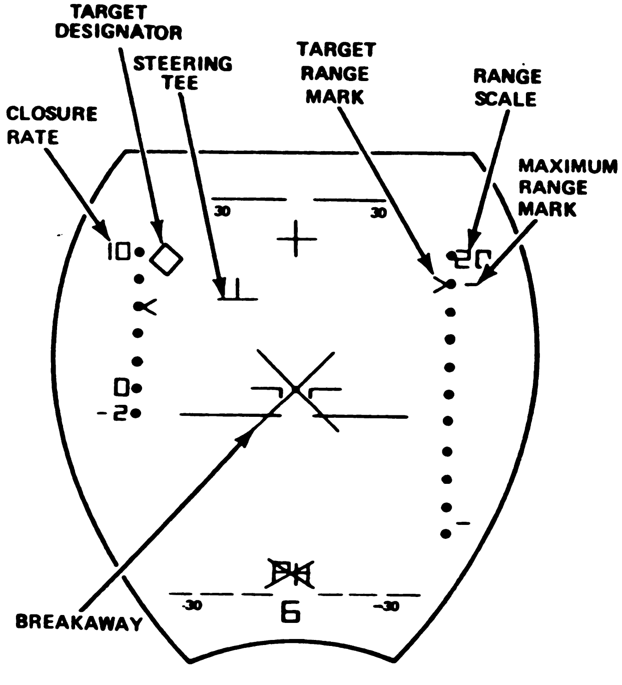
Figure 10-15.—Sparrow normal mode.



222.557

Figure 10-14.—Sidewinder normal mode.



222.559

Figure 10-16.—Phoenix normal mode.

Air-to-Ground

The air-to-ground mode is shown in figure 10-17. This mode is used primarily for the delivery of bombs or other types of air-to-ground weapons. Along with navigation information, it also displays bomb ballistic information along with target information.

Landing

The landing mode (fig. 10-18) gives the pilot altitude, vertical descent, angle of attack, and velocity information. This mode is used when making an approach to an airfield or a carrier until the pilot has visual contact with the ground.

SUMMARY

The modern electro-optical sight or head up display is a system capable of displaying various types of attack and flight information to the pilot. The HUD uses a cathode-ray tube as the display source. It uses a signal converter or a signal processor to convert the various aircrafts system information to usable information for the display unit.

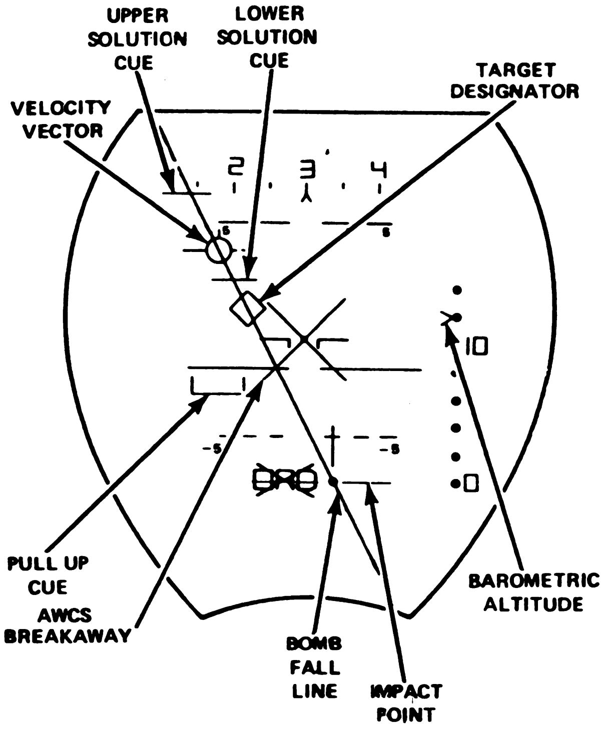


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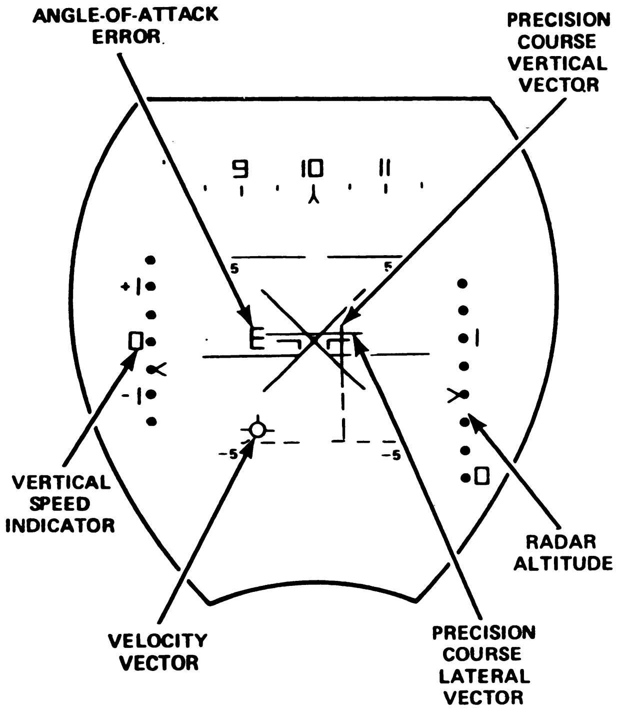
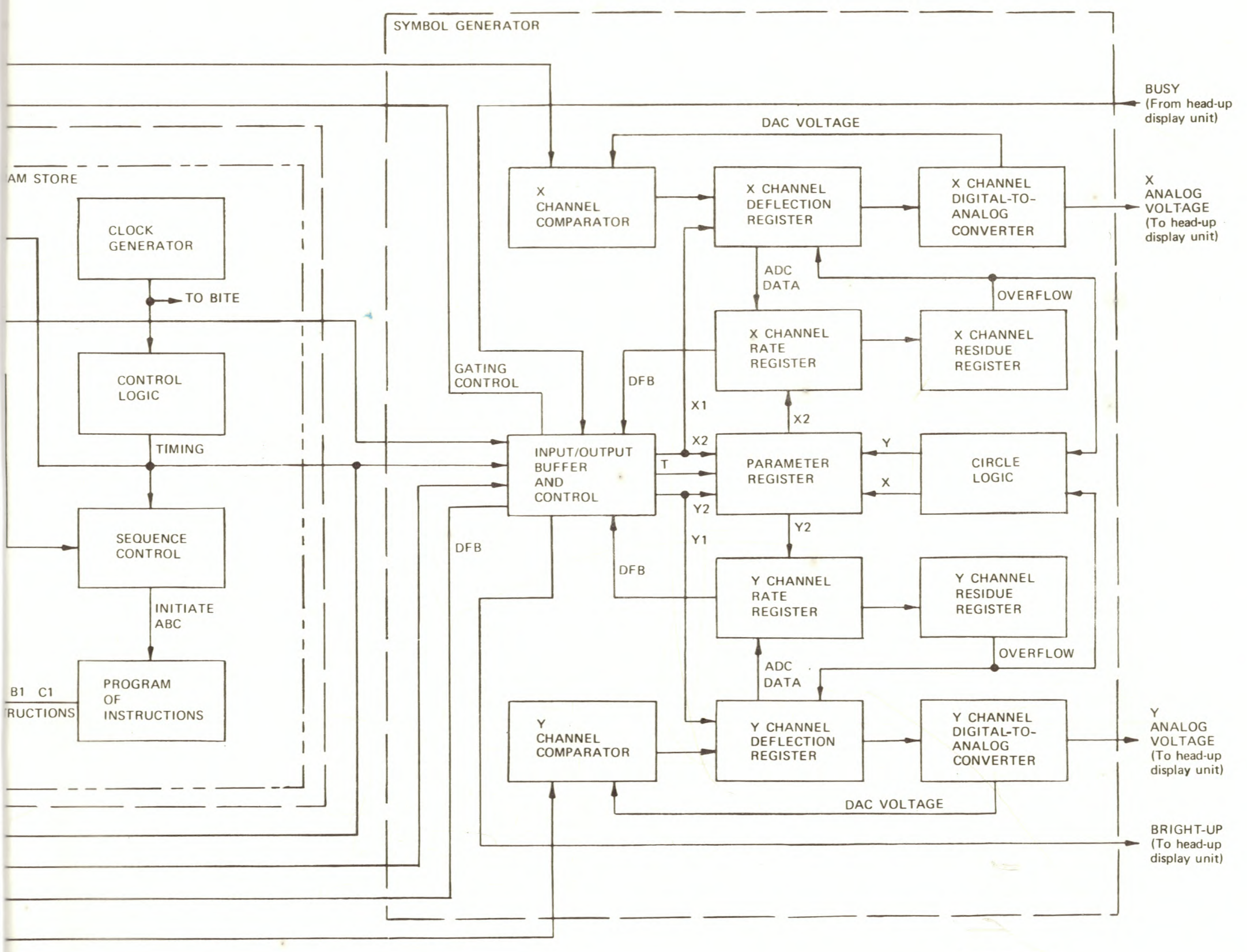
Figure 10-17.—A/G computer target mode.



222.561

Figure 10-18.—Landing mode.


SYMBOL GENERATOR
BUSY (From head-up display unit)
DAC VOLTAGE
AM STORE
X CHANNEL COMPARATOR
X CHANNEL DEFLECTION REGISTER
X CHANNEL DIGITAL-TO-ANALOG CONVERTER
X ANALOG VOLTAGE (To head-up display unit)
CLOCK GENERATOR
TO BITE
ADC DATA
OVERFLOW
X CHANNEL RATE REGISTER
X CHANNEL RESIDUE REGISTER
CONTROL LOGIC
GATING CONTROL
DFB
X1
X2
TIMING
INPUT/OUTPUT BUFFER AND CONTROL
T
PARAMETER REGISTER
Y
X
CIRCLE LOGIC
Y2
Y1
SEQUENCE CONTROL
DFB
DFB
Y CHANNEL RATE REGISTER
Y CHANNEL RESIDUE REGISTER
INITIATE ABC
ADC DATA
OVERFLOW
B1 C1
RUCTIONS
PROGRAM OF INSTRUCTIONS
Y CHANNEL COMPARATOR
Y CHANNEL DEFLECTION REGISTER
Y CHANNEL DIGITAL-TO-ANALOG CONVERTER
Y ANALOG VOLTAGE (To head-up display unit)
DAC VOLTAGE
BRIGHT-UP (To head-up display unit)

NOTES

A-A1-A2-A3-A4 = Digital computer data accumulation phase
B-B1-B2-B3-B4 = Digital computer data processing phase
C-C1-C2-C3 = Digital computer data output phase

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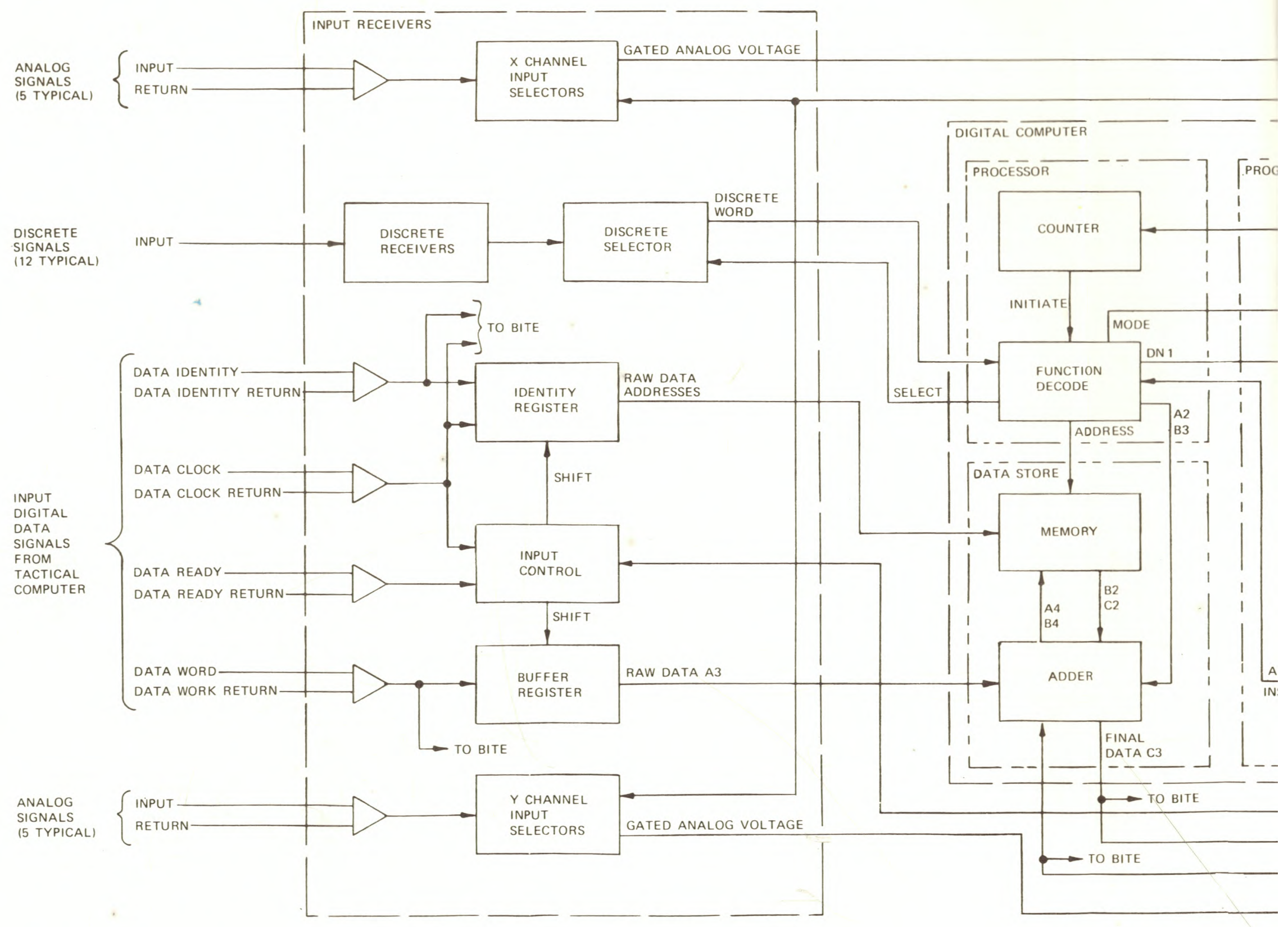
Figure 10-5.—Signal data processor signal flow diagram.

30112101044243-001
FLD00100030


INPUT RECEIVERS
ANALOG SIGNALS (5 TYPICAL)
INPUT
RETURN
X CHANNEL INPUT SELECTORS
GATED ANALOG VOLTAGE
DIGITAL COMPUTER
PROCESSOR
DISCRETE SIGNALS (12 TYPICAL)
INPUT
DISCRETE RECEIVERS
DISCRETE SELECTOR
DISCRETE WORD
COUNTER
INITIATE
MODE
TO BITE
DN 1
DATA IDENTITY
DATA IDENTITY RETURN
IDENTITY REGISTER
RAW DATA ADDRESSES
SELECT
FUNCTION DECODE
A2
B3
ADDRESS
DATA STORE
SHIFT
DATA CLOCK
DATA CLOCK RETURN
INPUT DIGITAL DATA SIGNALS FROM TACTICAL COMPUTER
MEMORY
DATA READY
DATA READY RETURN
INPUT CONTROL
A4
B4
B2
C2
SHIFT
DATA WORD
DATA WORK RETURN
BUFFER REGISTER
RAW DATA A3
ADDER
TO BITE
FINAL DATA C3
TO BITE
ANALOG SIGNALS (5 TYPICAL)
INPUT
RETURN
Y CHANNEL INPUT SELECTORS
GATED ANALOG VOLTAGE
TO BITE

CHAPTER 11

ELECTRIC POWER AND GROUND COOLING SYSTEMS

In order to operate and maintain the complex electronic installations of modern naval aircraft, you, as an AQ, must be familiar with the electric power system of the particular aircraft with which you are associated. Since the electronic installations of aircraft vary widely according to the size and configuration of the aircraft, the electric power requirements and the electrical system components of aircraft also vary. Therefore, you must also have a basic understanding of the component parts of the electrical system of a typical aircraft—the power generation equipment, the conversion units, the power control, regulation, protection devices, and the general power distribution systems.

You must understand the capabilities and limitations of the auxiliary power sources provided for use in ground servicing and maintenance of aircraft. You must observe and enforce all safety precautions and regulations concerning the use of the units.

You must also know the requirements for cooling the various electronic equipment while on the ground. You must be familiar with the sources of auxiliary air and cooling, and you must know the capabilities and limitations of the various cooling units.

This chapter discusses these topics. In most sections, the discussion is general. In a few instances, details are presented as they pertain to specific items of equipment. Coverage of equipment is limited to those expected to be in common usage during the life of this rate training manual.

AIRCRAFT POWER

The electric power system of an aircraft consists of the power source and its associated controls, the generation system and its associated control and regulation, the conversion units, the feeder and distribution system and its component parts, and the various protective devices used throughout the installation.

Most older types of aircraft used engine-driven generators to produce dc power at a nominal 27.7 volts. Inverters and dynamotors were used as conversion units to produce the voltages required for operation of the individual equipment. With the comparatively simple installations then in use, this arrangement was satisfactory; however, as the installations became more complex, weight problems arose. The increased weight (which resulted from the addition of more and more inverters and dynamotors) soon became prohibitive. A new approach to the problem was required.

As part of the overall effort to standardize aircraft and electronic installations, the supply and distribution of power offered a logical starting point. The first step was to standardize the supply voltages and power frequencies and to use generators which would provide the required power. Later in the standardization program, the generation of dc power was discontinued, and the primary power became exclusively ac. The dc requirement was supplied through transformer-rectifiers. This reduced the number of voltages generated, reduced the number of rotary devices, and allowed the use of smaller conductors in the distribution system. The result was a drastic decrease in the total weight of a given installation, which in turn permitted a more complex installation for a given weight allowance.

In order to be of any real value, a partial listing of the considerations involved in any discussion of aircraft electric systems must include the following items:

1. A "main generating source" refers to all generator units driven by a specified engine; thus,

a single-engine aircraft can have only one main source.

2. Multiengine aircraft may have a main generating subsystem for each engine. This is the usual practice, but it is not universally followed.

3. Adequate frequency regulation and stability in ac generation systems require some method of speed control of the generator's rotor drive mechanism.

4. Provisions must be made to ensure that adequate power is available in each mode of operation. In the event of failure of the aircraft engine or its associated generation system, the maximum amount of power which can be produced is decreased. In the case of single-engine aircraft, this automatically constitutes an emergency situation.

5. The failure of a single generator or engine in a multiple installation does not constitute the same degree of emergency as the same failure in a single-engine installation. Although some restrictions are placed on operational capabilities, some degree of safety may usually be maintained with the remaining engines and generators.

6. Provisions should be made to enable use of external power sources for starting the engines while on the ground and for ground operation without using the aircraft engines. The aircraft electric system must include provisions to prevent applying both internally generated power and externally furnished power to the system at the same time.

AIRCRAFT ELECTRIC SYSTEMS

The electric system of each model aircraft has some features peculiar to it alone, while other features are common to most models. In this section, you are presented with a general discussion of the electric system of a typical aircraft.

Source of Power

The basic source of power for the electric system is the aircraft engine. An ac generator requires a constant rotational speed in order to produce a constant frequency output. In most modern aircraft, a Constant Speed Drive (CSD) unit is inserted between the aircraft engine and the ac generator for this purpose.

The CSD unit acts as a variable-ratio differential transmission system which converts the variable speed of the engine to the constant speed required by the generator. The engine is mechanically coupled to the input of the CSD unit. The output of the CSD is mechanically coupled to the rotor of the generator. Internal coupling between the input and output sections of the CSD unit is usually hydraulic, using the engine's oil supply as the transmission coupling medium. Output speed of rotation is controlled by means of mechanical governors and/or electronic speed regulators.

Generation System

The heart of the electric generation system is the constant-speed, wye-connected ac generator. This unit normally produces a three-phase output voltage of about 120 to 208 volts at 400 Hz which is subsequently regulated to 115/200 volts. The basic theory of ac generators is discussed in NEETS, Module 5.

An underspeed switch is normally connected to the output shaft of the CSD unit. This is a centrifugally operated switch, and it is normally in the open position. It closes only when the output end of the CSD (which is also the generator shaft) reaches a preset speed of rotation. When the switch is open, the electrical system cannot be energized. An overspeed switch is sometimes used to prevent the generator from going too fast.

DC GENERATOR.—In most older aircraft, all electric power was generated as dc voltage. In most of the newer aircraft, no dc voltage is generated. The dc requirements are met by transforming and rectifying the ac. In some operational aircraft presently in service, however, the main power generation system provides both ac and dc voltages from a common unit. In other aircraft models, a separate generator is used to provide the dc power required for operation of the dc components. This method is not common in airborne applications because of the limited number of engines available. The basic theory of dc power generators is presented in NEETS, Module 5.

EMERGENCY GENERATORS.—In the event of failure or shutdown of the aircraft engines or main generators, the electric system becomes inoperative. The aircraft must have electrical power in order to maintain adequate flight control. All naval aircraft incorporate an auxiliary or emergency generator which operates independently of the aircraft engine.

The most common type of emergency generator is the ram air turbine (RAT). It is normally enclosed within the fuselage, being projected into the airstream when its operation is necessary. Driving power for the rotor is derived from the movement of a turbine through the air. It can be operated only in flight or with blast air when on the ground.

Due to its relatively small size, the emergency generator cannot supply the electric loads required for normal operation of the aircraft. Therefore, only those systems and equipment considered essential for the maintenance of flight are operable when the aircraft is dependent on the emergency generator.

Because the rotor of the ram air turbine generator turns at a variable speed (dependent on the speed of the aircraft in flight), frequency stability is not as refined as that of the main generators. The two methods most commonly used to control the frequency from becoming too high is the use of a governor and hydraulic pressure. No solution has yet been found for maintaining operation of the generator when the aircraft speed drops below a certain point. Therefore, in the event of a power-off landing, all electrical power and stability control are lost before the aircraft rolls to a full stop.

SYSTEM VOLTAGE REGULATION

Voltage regulators are incorporated in all electric generation systems. Although similar in basic purpose, the configuration and details of operation vary with each type. A typical solid state voltage regulator is shown in figure 11-1 and

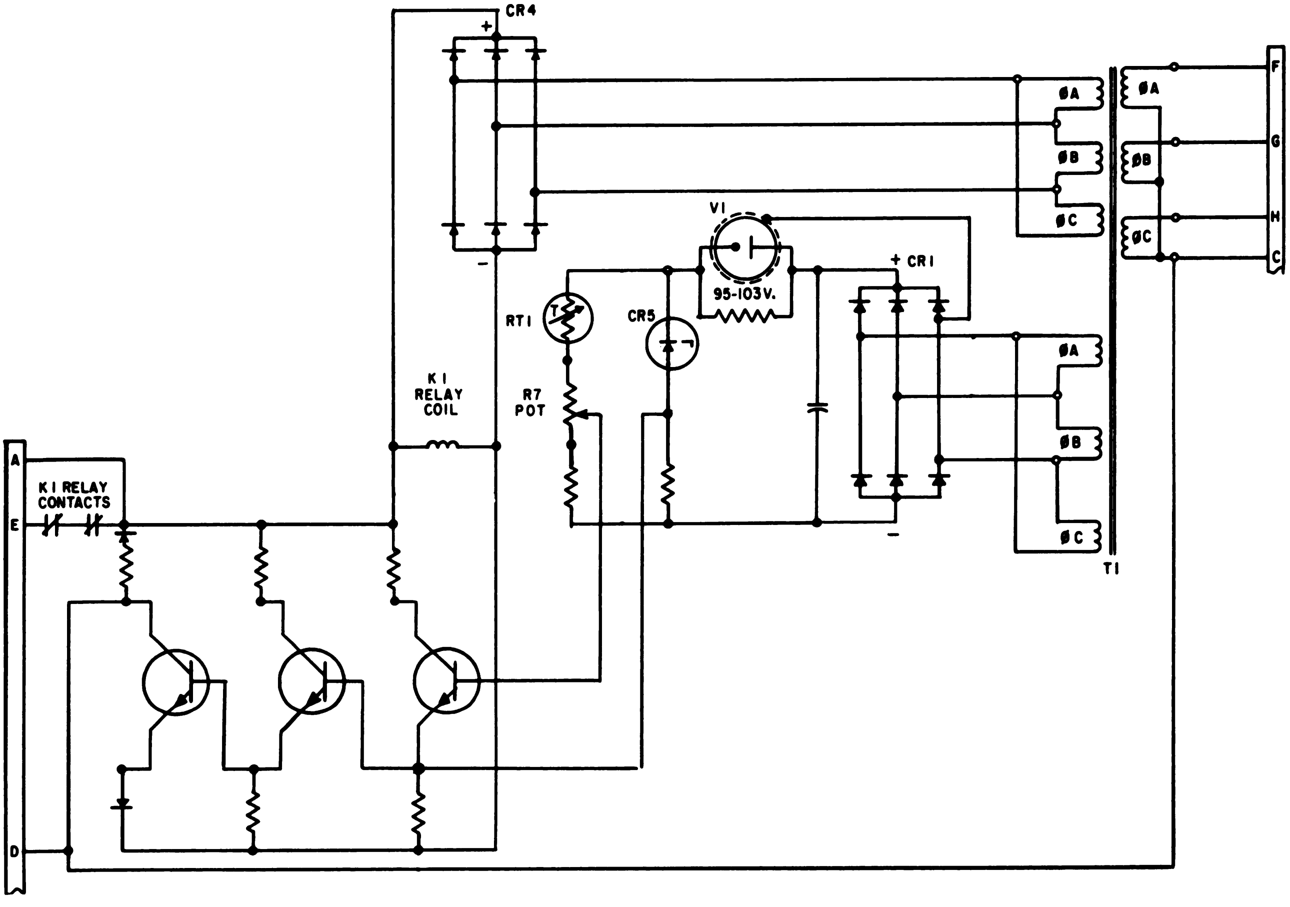


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Figure 11-1.—Solid state voltage regulator schematic.

discussed in the following paragraphs. You should refer to this figure while reading this section.

The solid state voltage regulator shown consists of a sensing circuit with input rectifiers, a temperature compensated Zener diode reference and error detecting bridge, and a three-stage transistor amplifier. The output of the bridge circuit is a voltage inversely proportional to the difference between the generator voltage and the regulator set voltage, and it is referred to as the error signal.

The output of the three-phase ac generator is supplied through transformer T1 in the regulator to provide isolation from the generator and to deliver correct utilization voltages. The output of the transformer is then passed through the full-wave bridge rectifier (CR1) to obtain a dc voltage to supply the comparison circuit. The output of the rectifier is proportional to the average of the three line voltages and is applied to the voltage reference and error detecting bridge. The voltage is then compared to the constant voltage present across the Zener diode (CR5).

NOTE: This ac voltage regulation controls current in the generator exciter field. As the voltage tends to rise, the dc exciter field current decreases causing the output of the generator to decrease. As the voltage decreases, the dc exciter field current increases causing the output of the generator to increase.

Potentiometer R7 permits adjustment to the desired voltage. The glow tube (V1) serves to increase the sensitivity of the voltage reference and error detecting bridge. Thermistor RT1 provides temperature compensation in the comparison circuit to offset the effects of changes in the other elements of the circuit resulting from temperature variations so that a nearly constant voltage is held.

EXTERNAL POWER

All aircraft have provisions for application of electric power from an external source for starting the aircraft engines and/or for ground servicing and maintenance without operating the engines. This power, while not generated within the aircraft, is part of the overall electric system of the aircraft. All aspects must be compatible with the power generated within the aircraft. Under no circumstances may the internal and external power be used at the same time. This is one of the functions of the distribution system which is discussed briefly below. The equipment used to supply power in the external mode of the electric system are discussed briefly in a later portion of this chapter.

DISTRIBUTION SYSTEM

Once the electric power has been generated and some of it transformed, it must be distributed to the various components and equipment where it is to be used. In a simple system, with comparatively few equipment and requiring only a single form of electric power, a simple distribution system could be used. In modern naval aircraft, however, with the complex electric and electronic installations requiring many forms of power, an extremely complex distribution system is required.

Each model aircraft has different electrical requirements; therefore, each distribution system must differ from all others in accordance with individual requirements. The major area of difference between distribution systems of different model aircraft lies in the switching arrangement used to change electric loads from one source to another in the event of a malfunction.

Long range patrol aircraft normally carry a flight engineer as part of its operating flight crew. The flight engineer is responsible for monitoring the operational status of many different systems within the aircraft. In some aircraft, the flight engineer is responsible for distributing individual electrical loads among the various sources to provide for essentially balanced loads. The flight engineer is usually responsible for recycling failed systems when it is assumed that the fault has been corrected. Interceptor and other carrier-based aircraft usually do not have a separate flight engineer. The distribution system for these two systems must be quite different in details, even though they may both incorporate all the basic requirements and capabilities for load distribution.

POWER CONVERSION DEVICES

In most naval aircraft, the main electric power generation system produces three-phase ac power at 400 Hz. All aircraft require various levels and quantities of dc power. In many instances ac power of a different frequency is also required. In these cases, various devices are needed to convert the power from the forms generated into the forms required for the specific application. A few important conversion devices are discussed briefly in the following paragraphs.

Transformer-Rectifiers

The most common conversion device for changing ac to dc is the transformer-rectifier. The three-phase, 115-volt ac is reduced in a stepdown transformer and then rectified to produce the 28-volt dc required for operation of various relays, lights, instruments, and mechanical devices. Specific transformer-rectifier units are discussed in the electrical section of the maintenance instructions manual (MIM) for each model aircraft. The fundamental theory of transformers is discussed in NEETS, Module 2.

Inverters

An inverter is a rotating electromechanical device used to convert low voltage dc into ac. It consists essentially of a speed-governed dc motor, an armature and brush assembly, and a permanent magnet inductor type ac generator all within a single unit. The armature and the permanent magnet rotor are usually mounted on a common shaft.

The inverter's output frequency and voltage should be checked periodically to assure that they are within prescribed limits. Should adjustment be required, the electrical shop is notified since adjustment of inverters is a responsibility of the AE rating.

Frequency Changers

When ac voltages of a frequency different from that produced by the main generator are required, suitable motor-generator combinations are used. Main electric power frequency is usually 400 Hz. Many aircraft provide a 60-Hz source for test equipment and an 800-Hz source for certain instruments or components.

F-14 ELECTRICAL SYSTEM

As you read this section, refer to the block diagram shown in figure 11-2, a foldout at the end of this chapter. The F-14 aircraft has four power sources as follows:

1. Left main generator.
2. Right main generator.
3. External power.
4. Emergency generator.

Alternating current is supplied by two 115/200 V ac, 400-Hz, three-phase, brushless engine-driven generators. These generators supply power to the main, essential and monitor ac busses. Either generator is capable of supplying the entire electrical requirements of the aircraft in the event one should fail. Dc power is derived from two transformer-rectifiers (TR) units.

The TRs are powered by their respective main ac bus. They convert 115 V ac to 28 V dc for distribution to the secondary bus system. Either TR is capable of supplying the entire dc requirements of the aircraft.

Emergency power is provided by a hydraulically driven, 5-KVA/50-amp generator. It provides both ac and dc power for essential equipment only. The emergency generator is automatically actuated upon multiple generator or multiple TR failure. Emergency generator operation terminates upon reactivation of either main generator.

External power is supplied to the aircraft main ac busses through an external ac power contactor. As shown in figure 11-2, the aircraft can only receive external or generator power at any one time.

CIRCUIT PROTECTION AND CONTROL

The electric system of an aircraft is protected from damage and failure by fuses, current limiters, and circuit breakers. Control and distribution of power is accomplished by the use of switches and relays. Each of these components is available in many styles and sizes, some of which are ideally suited for use in aircraft while others are limited to use in shop installations. In the following section, you will be presented with a brief discussion of these components.

FUSES

Fuses provide a controlled, intentionally weakened link in an electric circuit. They serve as safety devices in the event of undesired overloads. Fuse sizes are available with ratings as low as a few milliamperes to several hundred amperes. Fuses of most ratings are available for normal, slow-acting, or fast-acting operation.

A fuse is a heat-sensitive, heat-operated device. When operated at the rated current, it consumes electrical power and dissipates this power in the form of heat. Under normal operating conditions, the dissipated heat is not sufficient to cause the unit to fail. However, when the fuse is operated above the normal current rating, the overload current generates additional heat which melts the fusible element.

Voltage Rating

A fuse can be operated at any circuit voltage if it is mounted in a sufficiently well-insulated holder (as long as the fusible element is able to fail without suffering arc damage). When a fuse fails due to excessive current, the full circuit voltage appears across the open fuse. If inductance is present in the circuit, a surge is generated which may cause a destructive arc to be formed within the fuse. Under these conditions, intense heat and pressure develop, and the fuse may literally explode.

Fail-Time Characteristics

The fail-time characteristic of a fuse depends on the percent of rated current and thermal inertia of the fuse. Overload currents (currents larger than the maximum value for which the fuse is rated) when flowing through a fuse, heat the element beyond normal capacity. After a period of time, the fusible element fails.

Fuse elements with a large thermal inertia increase the length of time before failure. Fuses containing such elements are known as slow-acting, slow-blow, or time-delay fuses. Slow-acting fuses are constructed with a compound element—a thermal cutout and a fusible link that melts on short circuits on very high overloads. Small, light fuse elements reduce the thermal inertia and therefore are faster acting. This type of fuse is known as a fast-acting fuse and is used principally for the protection of sensitive instruments.

In the selection of a fail-time characteristic, both the steady state and the transient or surge currents are considered. If currents of 200 to 400 percent above normal can be tolerated for periods of 1 to 10 seconds, a slow-acting fuse is specified. If the circuit requires immediate protection for any current above normal, a fast-acting fuse is specified. If the current must be limited to 200 percent of the rating for periods less than 1 second, then a normal or medium fail-time characteristic is specified. (See figure 11-3.)

When possible, a fuse should be operated at about 75 percent of its rated value. This provides a good balance between protection and reliability.

Vibration Resistance

Fuse protection for equipment subject to vibration can be provided by special vibration-resistant construction. This type of fuse has a spring formation, with wing-like extensions which bear on the inside wall of the glass body to decrease vibration of the fuse element. For slow-acting fuses, a different construction is used. This construction consists of a compound spring and link structure. On moderate overloads, as the compound element reaches the melting point, the

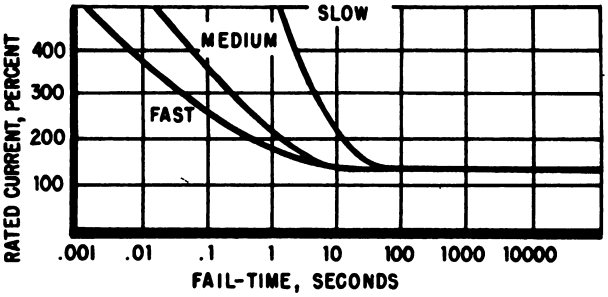

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Figure 11-3.—Fail-time characteristics of fuses.

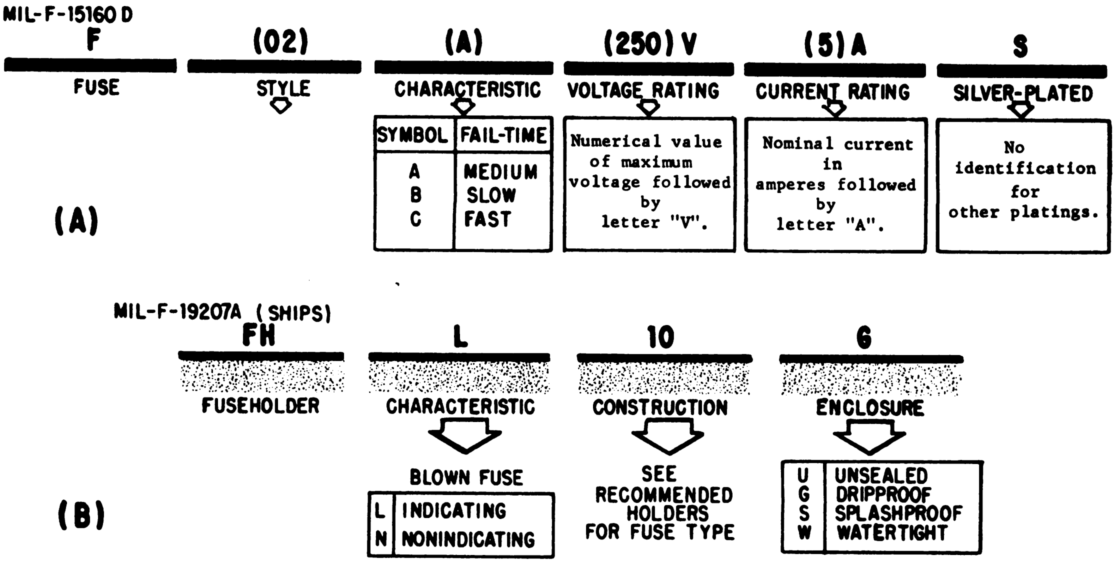

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Figure 11-4.—Identification coding: (A) fuses; (B) fuse holders.

spring pulls away from the link, while on short circuits, the link fails.

Identification Coding

Fuses and their corresponding fuse holders are numbered according to a standardized system for easy identification. The numbering system is shown and explained in figure 11-4. Some actual fuses are shown in figure 11-5.

Fuse Holders

The most common class of fuse holders used in Navy equipment is the post-type holder shown in figure 11-5. It may be a screw-in or a bayonet type. Both of these types are securely mounted to the chassis or front panel of the equipment. The purpose of the holder is the same, regardless of type—to hold the fuse securely with good electrical connection and physical stability for protection from mechanical vibration and electrical short circuit.

You should use care to ensure that the fuse is of a physical size compatible with the holder. Fuses which are undersized allow physical movement and arcing. This results in a blown fuse, erratic operation, or a damaged holder. Fuses which are too large may cause cracking or breaking of the holder. Force should never be applied to either the fuse or the holder, since most are fragile devices.

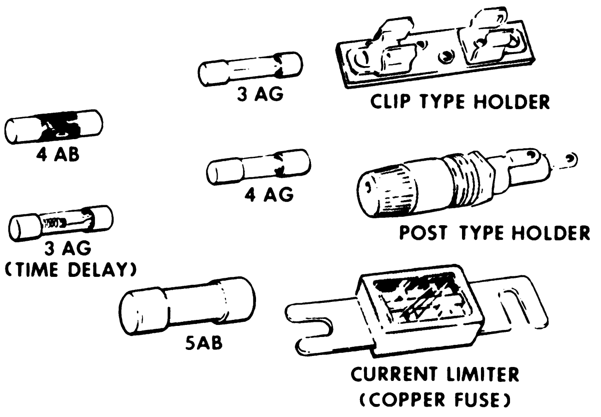

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Figure 11-5.—Aircraft fuses and fuse holders, typical examples.

Post type fuse holders are normally series-connected in the line, with the end connection to the power source and the center connection to the load. When connected in this fashion, the equipment is protected in the event of a broken holder. A short circuit from fuse holder to chassis ground will result in a blown fuse and excessive current will not flow. Reversed connections will not furnish this protection. Connection is normally made by solder, although some fuse holders are connected by use of a screw and lug method.

CURRENT LIMITERS

Devices somewhat similar to fuses, called current limiters, are used in aircraft circuits that carry high currents. (See fig. 11-5). The current limiter consists of a copper link of carefully predetermined sections. The sections melt when abnormally high currents start to flow. The melting sections have a high-arc resistance to keep the circuit current within the capacity of the limiter. If the excessive current is only a temporary surge, the melting ceases and the circuit continues to operate as if no abnormal current had been present. Repeated applications of excessive current or uninterrupted application for a period of several seconds melt through the sections and cause the limiter to function in the same manner as a fuse.

CIRCUIT BREAKERS

In modern naval aircraft, circuit breakers have replaced fuses as the main circuit protection device for most of the wires and cables making up the electrical system. The circuit breaker is designed to open the circuit under short-circuit or overload conditions without injury to itself. Thus, it performs the same function as the fuse, but it has the advantage of being reset and used again. Circuit breakers are rated in amperes and volts.

There are three basic types of circuit breakers—thermal, magnetic, and thermomagnetic. The following discussion is slanted toward the thermal type, because this type is more widely used. Circuit breakers are divided into three categories—the pushbutton reset type, the toggle type, and the automatic reset type (sometimes called a circuit protector).

The pushbutton reset type (fig. 11-6), consists of a bimetallic, thermally actuated, spring-loaded device which connects two electrical contacts when set. An excessive current through the device causes an uneven expansion of the bimetallic mechanism (thermal release). This action releases a trigger escapement and permits the spring-loading to separate the contact members.

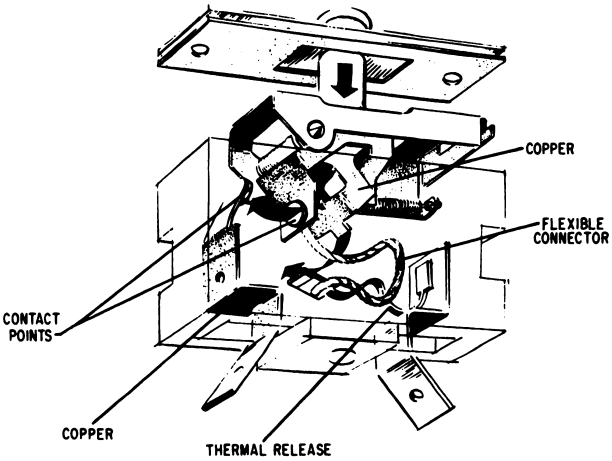

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Figure 11-6.—Thermal circuit breaker.

A visual indication of the automatic opening is provided by causing the pushbutton to move to an easily noticed "tripped" position. In this position, the button is fully extended and the white ring of the button is showing. The latest type of pushbutton breaker has a pullout feature which permits manual opening of the circuit.

Another type of circuit breaker uses a toggle lever instead of the pushbutton. It operates in the same manner as the pushbutton reset-type breaker, except that the tripped condition is indicated by the toggle lever being in the OFF position. This type of circuit breaker has the apparent advantage of also being used as a switch.

Manual resetting of the circuit breaker may be accomplished by means of the actuator (either pushbutton or toggle lever) whenever the bimetallic thermal element cools sufficiently for the trigger to engage its latching mechanism. In connection with resetting, there are two classifications for circuit breakers—trip-free and nontrip-free.

The nontrip-free circuit breakers can be prevented (by the operator's action) from tripping even though a tripping condition exists. This should be done only in an emergency. Since this action is apt to change the calibration, the breaker should be replaced as soon as conditions permit. This type breaker is no longer being installed in new aircraft, but it is still found on some older models.

In the trip-free class, the contacts cannot be kept closed by holding the actuator in the closed (or reset) position as long as an overload condition persists which would otherwise cause normal tripping.

A disc type thermal circuit breaker is shown in figure 11-7. This breaker consists of a conductive, snap-acting bimetallic disc which bridges two electrical contacts. When the disc is heated by the excess current through it, it snaps to the reverse position, opening the contacts and breaking the circuit. In circuit breakers having low ratings, a resistance wire is inserted. Current through this wire provides the heat necessary to snap the disc. These breakers are reset by pressing a button which restores the disc to its original position. When circuit breakers of this type are closed, they cannot be reopened manually. They are also nonindicating; that is, the position of the breaker (open or closed) cannot be determined by visual inspection.

The automatic reset-type circuit breaker is similar to the bimetallic-disc type just described, except that it has no reset pushbutton. It resets itself automatically. After a short time, when the disc has cooled sufficiently, it will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

Another type of circuit breaker is the switch toggle variety which is based on magnetic instead of thermal operation. This type can be made to open almost instantly when more than the rated current flows in the circuit. An electromagnet is placed in series with the spring-loaded contacts. The contacts are mounted so that an armature acts as a latch to hold them closed. When an excess current flows, the armature is pulled toward the electromagnet, releasing the contacts and opening the circuit. To reset the circuit breaker, the contacts are closed manually and the spring-loaded armature returns to its normal position.

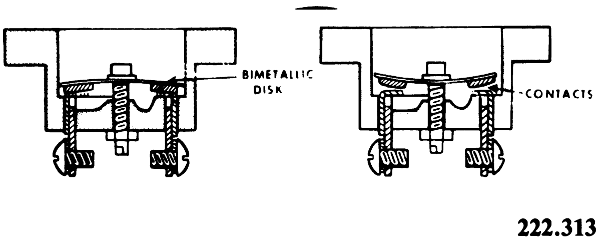

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Figure 11-7.—Thermal circuit breaker (disc type).

AUXILIARY POWER SOURCES

The electric power requirements for starting and servicing modern aircraft are very high. Even in those aircraft which have batteries installed, routine servicing and operational testing of the electronics system require that either the aircraft engines be operating or that an external source of electric power be used.

There are many auxiliary power units (APUs) available for supplying electric power to the aircraft for engine starting, ground servicing, and operational testing. External power receptacles are mounted on all aircraft to provide a means of connecting the external sources to the aircraft.

Some aircraft are also furnished with an airborne auxiliary powerplant installed aboard or attached externally to the aircraft. The auxiliary powerplant usually consists of an independently operated gasoline engine or turbine which drives a generator. The generator supplies power to the electric system on the ground and in the air. Although the airborne auxiliary powerplant is not capable of supplying the entire load requirements for normal operation of all equipment, it does have the capacity to furnish limited loads for ground servicing or for emergency use in flight.

In this section, you will be presented with a brief overview of ground- and ship-based auxiliary power units and with the main power sources normally found in aircraft hangars and on carrier flight decks.

AUXILIARY POWER UNITS

In this discussion, the term auxiliary power unit (APU) is limited to those units which are portable but are not installed aboard the aircraft. The units may be self-propelled, towable, or merely transportable. They may use diesel fuel, jet fuel, or gasoline. Several types of APUs are discussed. However, before beginning a discussion of specific types of individual models, several safety precautions are mentioned.

When moving the APU near the aircraft, care should be taken to avoid colliding with aircraft or other equipment. Flight lines and aircraft parking areas are normally crowded, and space between aircraft and equipment may not be sufficient to allow passage of the APU. Equipment and/or aircraft may have to be moved and repositioned to permit access to the aircraft to be serviced. When movement of the aircraft is necessary, the line crew should be notified and requirements should be outlined. Local procedures and policies must be followed and line safety regulations observed. The APU should NEVER be used to move the aircraft, not even "a couple of feet."

Once access to the aircraft has been gained, the APU is connected to the aircraft. Each unit has its own procedures for operation, but some general considerations apply to all. Prior to connecting the APU to the aircraft to be serviced, all aircraft power switches should be checked and placed in the proper position. This requires that you be familiar with the aircraft. The information is available in the flight manual and in the MIM for each model aircraft.

Prior to making the actual connection, the cable and the receptacle should be inspected carefully for general condition and for correct polarity/phase. Many flights are aborted because external power cables have been inserted into aircraft with polarity or phase reversed due to careless insertion or defective cables.

The APU should not be connected to the aircraft with a "hot line." The generator power switches should be off. After connection, the generator may be activated, and the switches turned on when stable operation is obtained.

During high load operation of APUs, the power cables frequently heat excessively and the cable voltage drop is quite noticeable. Nearly all of the mobile electric powerplants (MEPPs) have an output current capability well in excess of the current rating of the cables. Therefore, when supplying power to large loads, the current ratings of the cables must be considered. If the load requirements exceed the rating of the cable, the load should be reduced, or an APU with a higher capacity cable should be obtained.

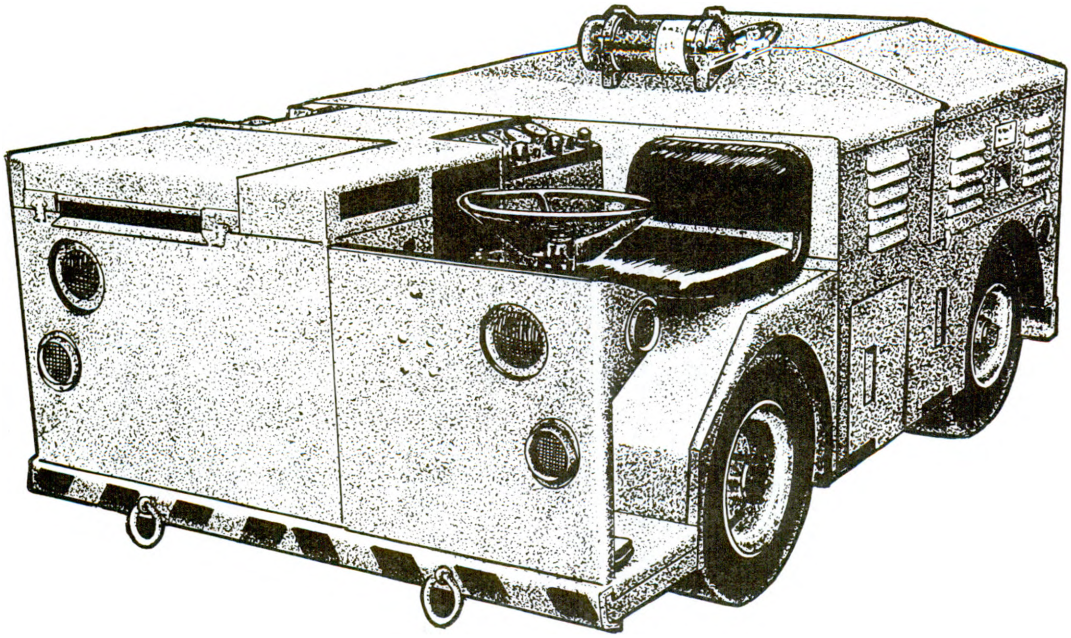

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Figure 11-8.—MEPP NC-2A.

MOBILE ELECTRIC POWERPLANTS (MEPPs)

The NC-2A (fig. 11-8) is a self-propelled, diesel-engine-powered service unit. It is front-axle driven, steered by the two rear wheels, and it is readily maneuverable in congested areas. The front axle is driven by a 28-volt dc, reversible, variable-speed motor which is capable of propelling the unit up to 14 mph on level terrain. The unit has a turning radius of approximately 11 feet.

This unit supplies 30 KVA, 120/208 volt, 400-hertz, three-phase power for servicing, starting, and maintaining jet aircraft. A dc generator produces 28 volts up to 500 amperes.

The primary source of power is a three-cylinder, water-cooled diesel engine which drives the ac and dc generators through a speed-increasing transmission. All controls, both propulsion and electrical power, are available to the operator on three panels located in the front and to the right of the operator's seat. The unit is intended primary for shipboard use.

The NC-8A shown in figure 11-9 is a mobile, self propelled unit used for serving and starting aircraft. It is powered by a four-cylinder, two-stroke cycle, diesel engine. The NC-8A has one dual-purpose generator which is capable of supplying both ac and dc power at the same time. This unit provides 28 volts, 500 amperes continuously, or 28 volts, 750 amperes intermittently; and 120/208-volt, three-phase, 400-Hz, 60 KVA ac power. When both dc and ac power are used at the same time, ac power is limited to 34 Kw.

All engine controls and instruments are located directly in front of the operator. Controls and instruments for the generator are located to the operator's right. Vehicle propulsion power is provided by a 28-volt, direct-current, reversible, variable-speed motor. This unit is used primarily for shore-based operations.

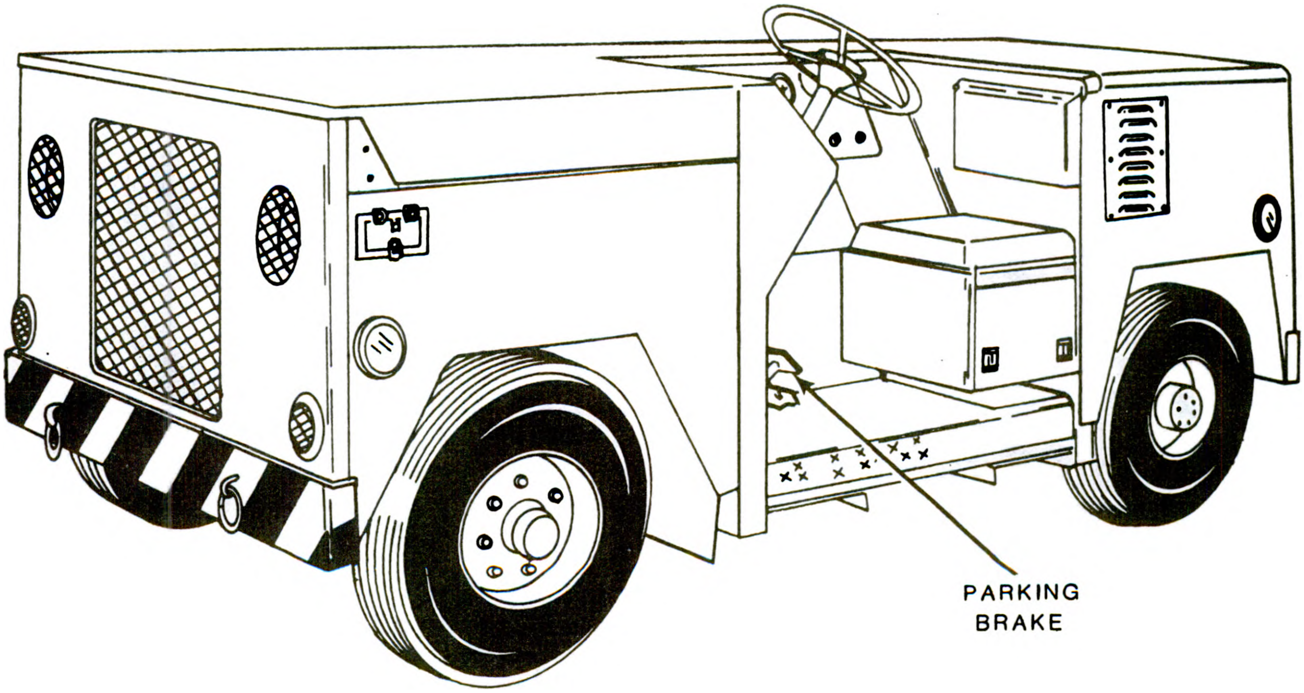

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Figure 11-9.—MEPP NC-8A.

The NC-10B (fig. 11-10) is a diesel-engine driven unit designed for shipboard or shore station use. This unit supplies 90 KVA, 120/208 volt, three-phase, 400-Hz power for servicing, starting, and maintaining aircraft. A portion of the electrical power generated is rectified to supply 28 volts dc at 750 amperes (1,000 amperes intermittent) for aircraft starting.

This unit is self-propelled by two hydraulic wheel motors for movement between aircraft on the line. The operator's control is located on the towbar. Power generation is controlled by the operator from the control panel located at the right front of the unit.

The NC-12A shown in figure 11-11 is a fully enclosed, diesel-engine-driven, dual-output powerplant. It provides a 120/208-volt, three-phase, 400 Hz, 125-KVA output; or a 87.5 KVA ac power at the same time with 750-ampere, 28-volt dc output. A dc output of 950 amperes can be obtained intermittently when only dc power is being used.

The powerplant and its components are mounted on a four-wheel trailer equipped with mechanical rear wheel brakes. These brakes are actuated by a hand lever, or by the spring-loaded tow bar. These units are not equipped with self-propelling features and must be towed. They are intended primarily for shipboard use.

The RCPT-105 shown in figure 11-12 is a gas-turbine-driven aircraft ground service unit. It is mounted in a low-silhouette, self-propelled trailer. The low silhouette design and self-propulsion system enable this unit to be maneuvered in

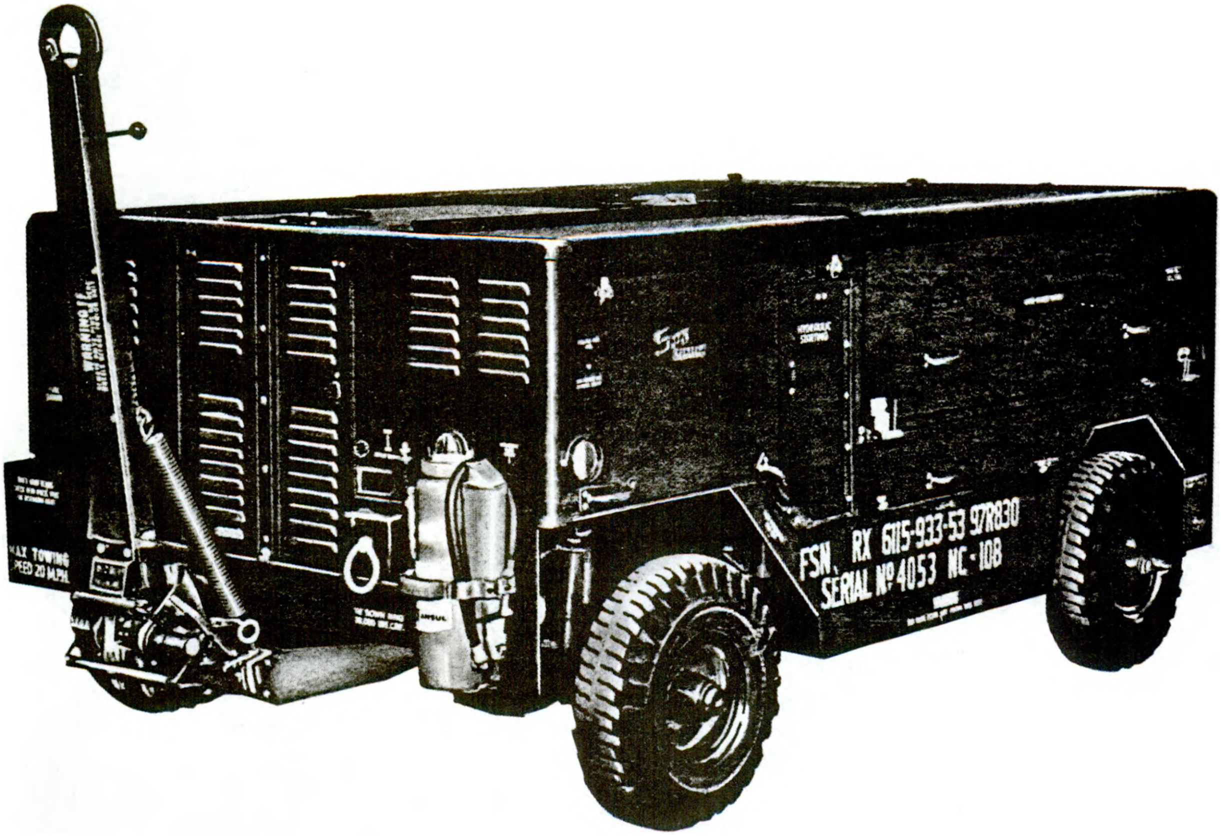

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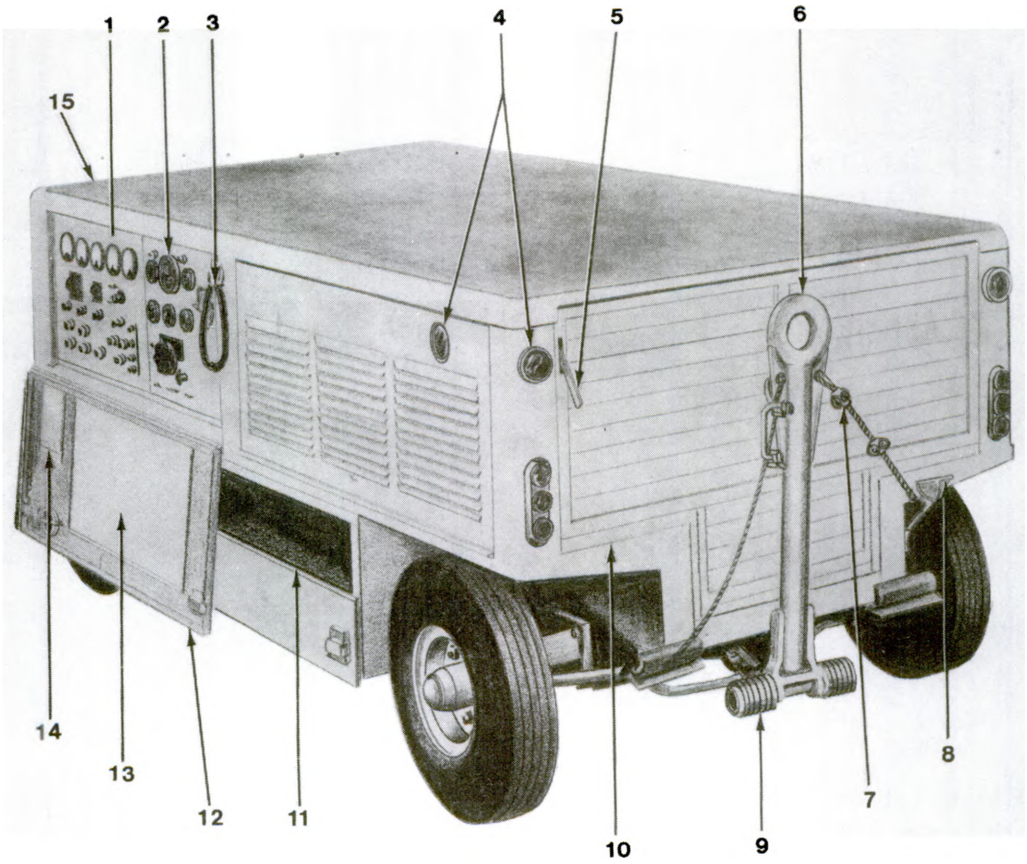
Figure 11-10.—MEPP NC-10B.



1. Electrical control panel.
2. Engine control panel.
3. Chain strap.
4. Safety reflectors.
5. Manual shutter control lever.
6. Tow bar.
7. Safety cable.
8. Parking brake lever.
9. Tow bar return springs.
10. Automatic shutters.
11. Output cable storage.
12. Control panels access door.
13. Schematic diagram encapsulation.
14. Lubrication diagram encapsulation.
15. Floodlight mounting location.

225.139

Figure 11-11.—MEPP NC-12A.

congested aircraft parking areas. It is completely self-contained and provides compressed air for starting the main engine. It also supplies 115/208-volt, three-phase, 400 Hz, 60-KVA ac power as well as 28 volt dc and 150 ampere maximum. All controls and instruments for the unit are grouped, by system, on one panel located at the right rear of the unit. This unit is intended primarily for shore-based use.

Mobile motor-generator sets (MMGs) perform the same function as the mobile electric powerplants, but they are not self-contained and require an external source of electric power. The MMGs are primarily used in hangar or shore stations, or on the hangar decks of aircraft carriers where the running of an internal combustion engine would be objectionable.

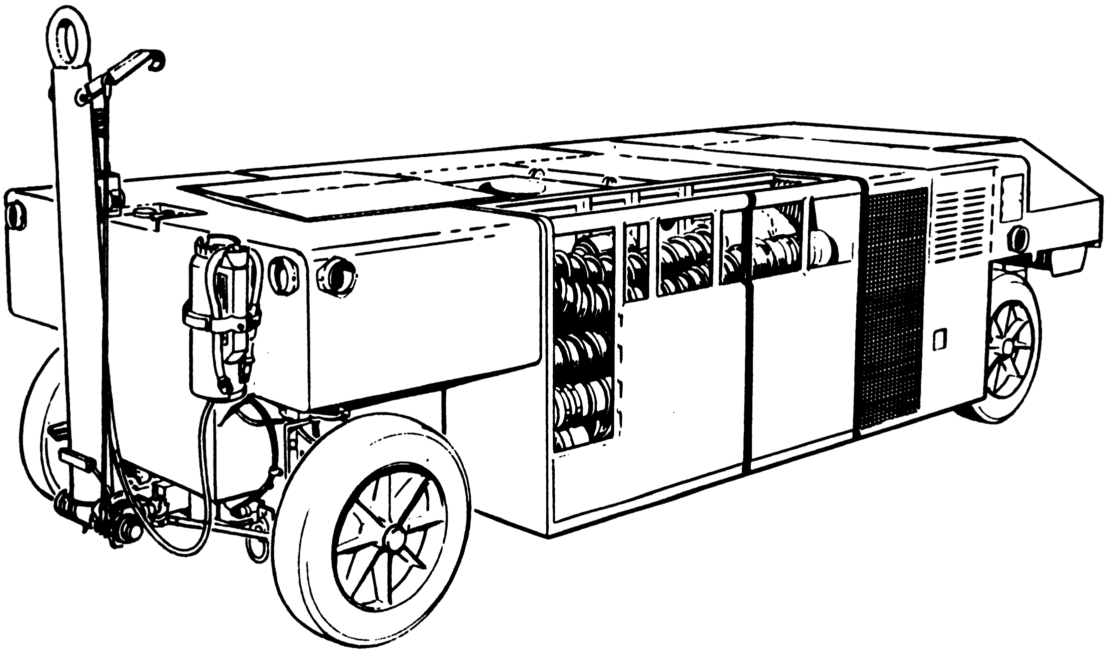


Figure 11-12.—RCPT-105.

The MMG-2 shown in figure 11-13 is physically quite small and very compact. It is a trailer-mounted electric-motor-driven generator set used to provide 120/208 volt, 400-Hz, ac power and 28 volt dc power for use in ground maintenance, calibration, and support for all aircraft.

DECKEDGE POWER

The primary function of the deckedge electric power system installed on aircraft carriers is to provide a readily accessible source of servicing and starting power to aircraft at all locations on the carrier's flight and hangar decks. The 400-Hz, three-phase ac servicing voltage is usually supplied by ac generators through stepdown transformers. Figure 11-14 shows a diagram of an electric system which may be found on a modern carrier. The deckedge power may be supplied by service outlets at the edge of the flight deck or from recesses in the flight deck. All systems have standard remote control switches, service outlet boxes, and portable cables.

Although there are some variations between the deckedge power systems of carriers of different classes and aircraft of different models, this discussion covered a typical system. For details concerning a specific installation, observe local instructions and safety precautions.

GROUND COOLING EQUIPMENT

The purpose and need for ground cooling will vary with type of aircraft and climatic conditions. When repairing high-voltage equipment aboard large aircraft in a tropical zone, ground cooling of the aircraft cabin reduces the hazard of shock due to clothing being wet with perspiration. It may also prevent shorting of components by falling perspiration.

A primary reason for using ground cooling equipment, even in temperate zones, is that electronic equipment produces large quantities of heat. This heat must be dissipated or the equipment would achieve temperatures that could cause damage and create a fire hazard.

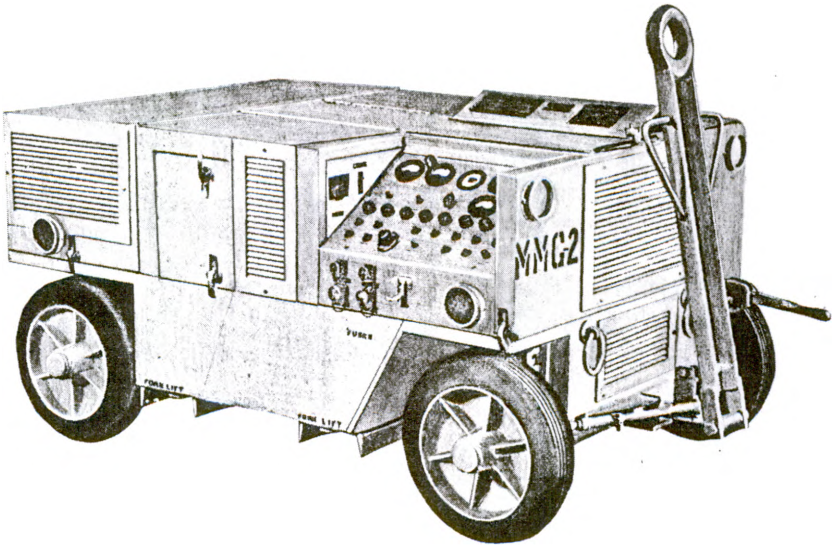


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Figure 11-13.—MMG-2.

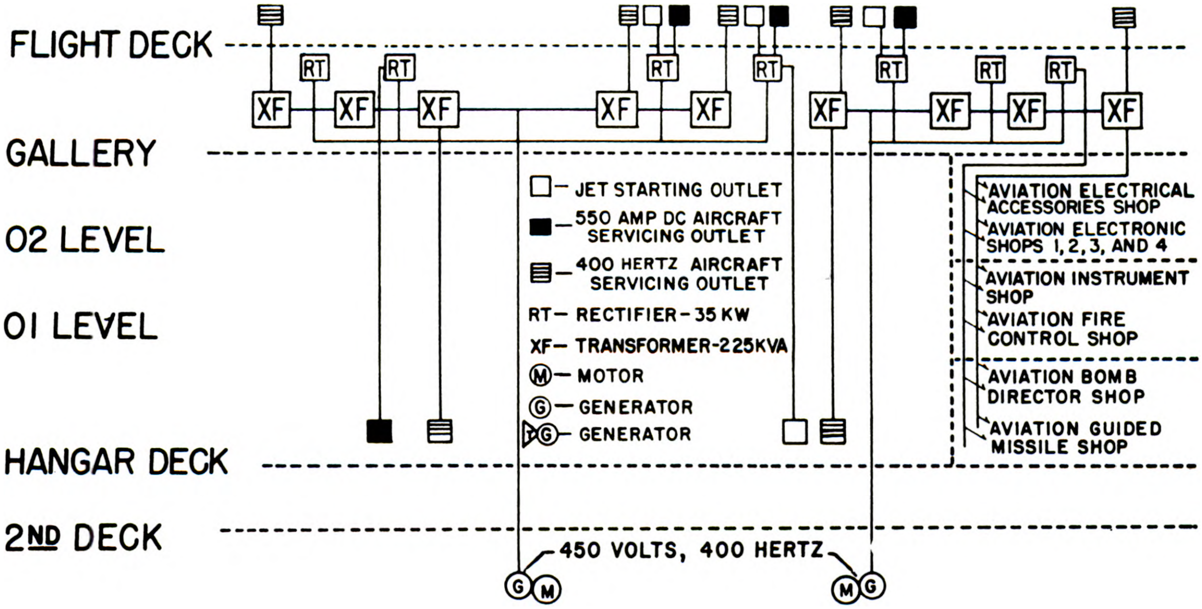
FLIGHT DECK
GALLERY
02 LEVEL
01 LEVEL
HANGAR DECK
2ND DECK
RT
XF
☐– JET STARTING OUTLET
■–550 AMP DC AIRCRAFT SERVICING OUTLET
▤–400 HERTZ AIRCRAFT SERVICING OUTLET
RT– RECTIFIER-35 KW
XF– TRANSFORMER-225KVA
Ⓜ– MOTOR
Ⓖ– GENERATOR
Ⓖ– GENERATOR
AVIATION ELECTRICAL ACCESSORIES SHOP
AVIATION ELECTRONIC SHOPS 1, 2, 3, AND 4
AVIATION INSTRUMENT SHOP
AVIATION FIRE CONTROL SHOP
AVIATION BOMB DIRECTOR SHOP
AVIATION GUIDED MISSILE SHOP
450 VOLTS, 400 HERTZ
G
M
M
G

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Figure 11-14.—Deckedge electrical system.

When the aircraft is airborne, various means are used to accomplish the required cooling. Some electronic equipment has fans built in for cooling. Others generate so much heat that a blast of air from outside the aircraft must be used. Some large magnetrons are liquid cooled. The liquid is cooled by air directed over a radiator.

When a large quantity of air is required for cooling, a common source for this air is the aircraft's ventilation system. Line maintenance, ground operational checks, and functional checks are usually performed without the aircraft's ventilation system operating since this system is driven by the aircraft engines. Therefore, a substitute air supply must be provided for the air distribution system. The mobile air conditioner was designed for this purpose.

The NR-2B shown in figure 11-15 is a mobile, trailer mounted, electrically powered, self-contained air conditioner. It requires a 400-volt, three-phase, 60-Hz power supply and has a cooling capacity of seven tons. The NR-2B can be used either for shipboard or for shore station operation.

The NR-5C shown in figure 11-16 is a mobile, trailer-mounted, electrically powered, self-contained air conditioner. It requires 440-volt, three-phase, 60-Hz power supply and has a cooling capacity of 22 tons. The NR-5C can be used equally well for either shipboard or shore station use.

The NR-10 shown in figure 11-17 is a mobile, trailer-mounted, diesel-engine-powered, self-contained air conditioner. It is powered by a six-cylinder, liquid-cooled, turbocharged, diesel engine and has a cooling capacity of 19 tons. The NR-10 is usually not used aboard ship because of its height.

SUMMARY

In this chapter, you have seen that aircraft electrical systems consist of an ac generator, a

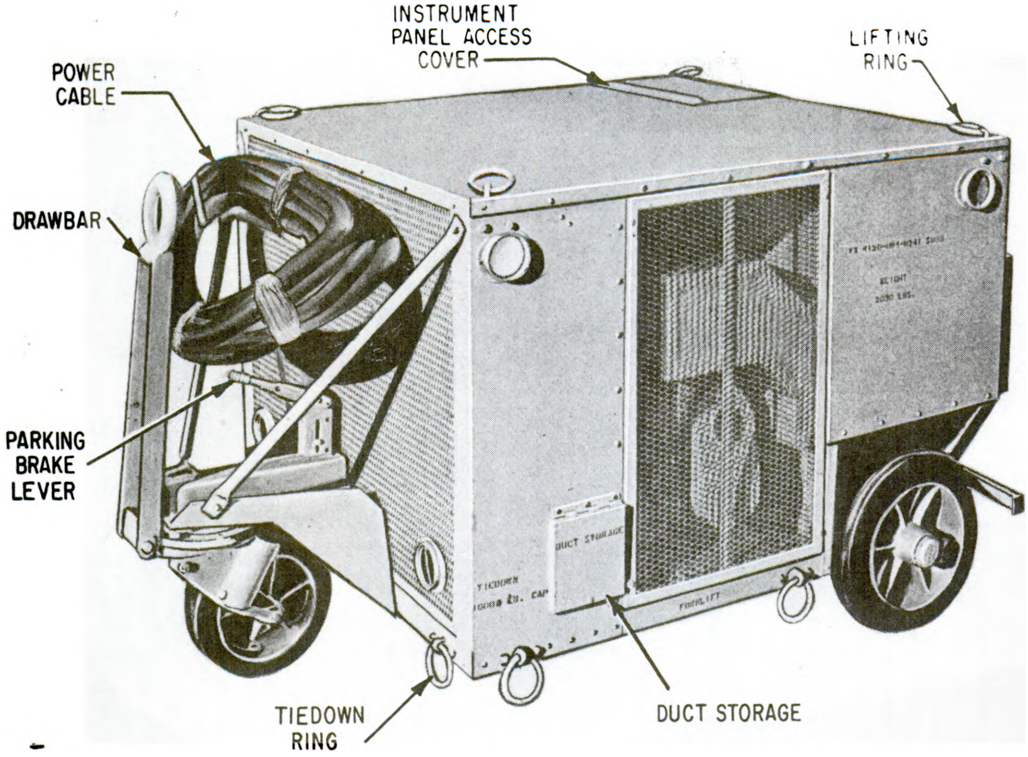

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Figure 11-15.—NR-2B mobile air conditioner.

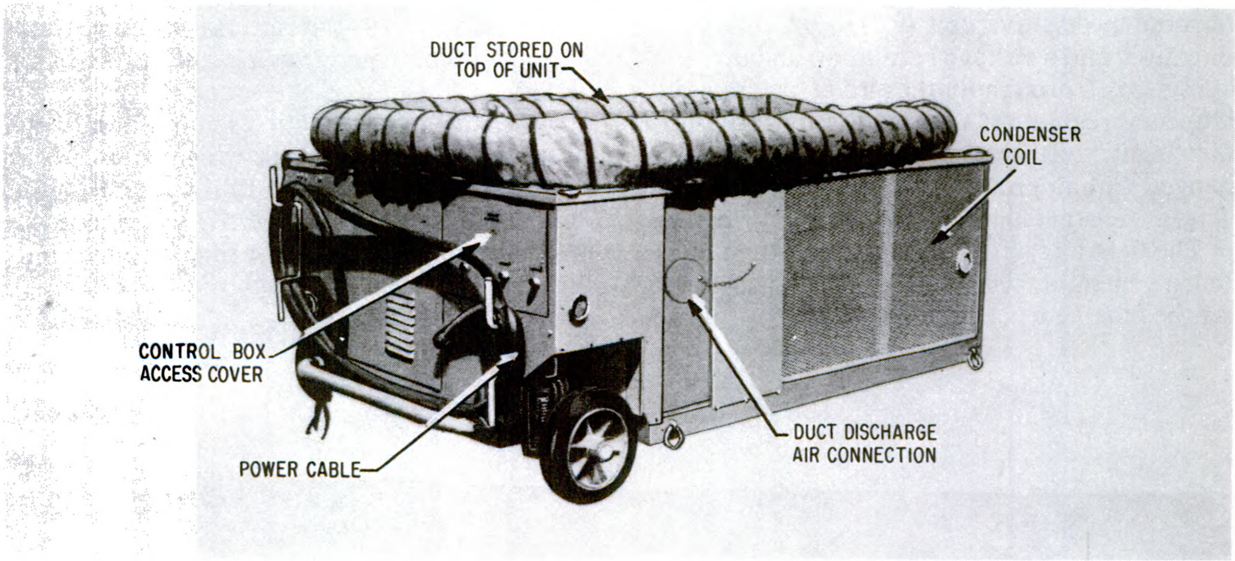

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Figure 11-16.—NR-5C mobile air conditioner.

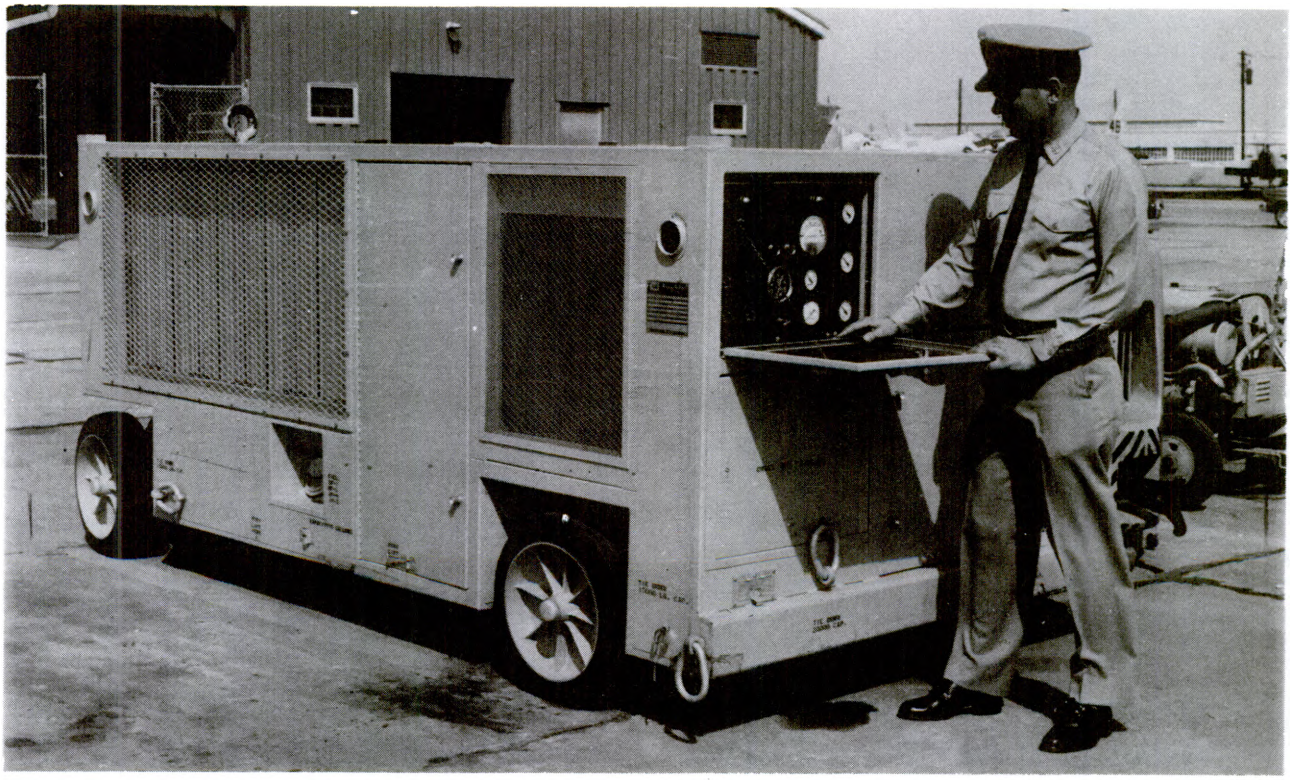

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Figure 11-17.—NR-10 mobile air conditioner.

constant speed drive unit (CSD), an emergency generator, and a voltage regulation and distribution system. Throughout the aircraft, voltage and frequency regulation is provided by the use of transformer rectifiers, inverters, and frequency changes. Circuit protection is provided by the use of fuses, current limiters, and circuit breakers.

The F-14 aircraft uses four sources of power: the left generator, right generator, external power, and the emergency generator. These four power sources provide the aircraft's power under normal flight, emergency conditions, and ground operations.

Auxiliary power sources and ground cooling equipment are used to provide the proper electrical power and cooling to the aircraft systems during ground operation and maintenance. These power sources provide a means of operating the aircraft's systems without the aircraft engines being operated.

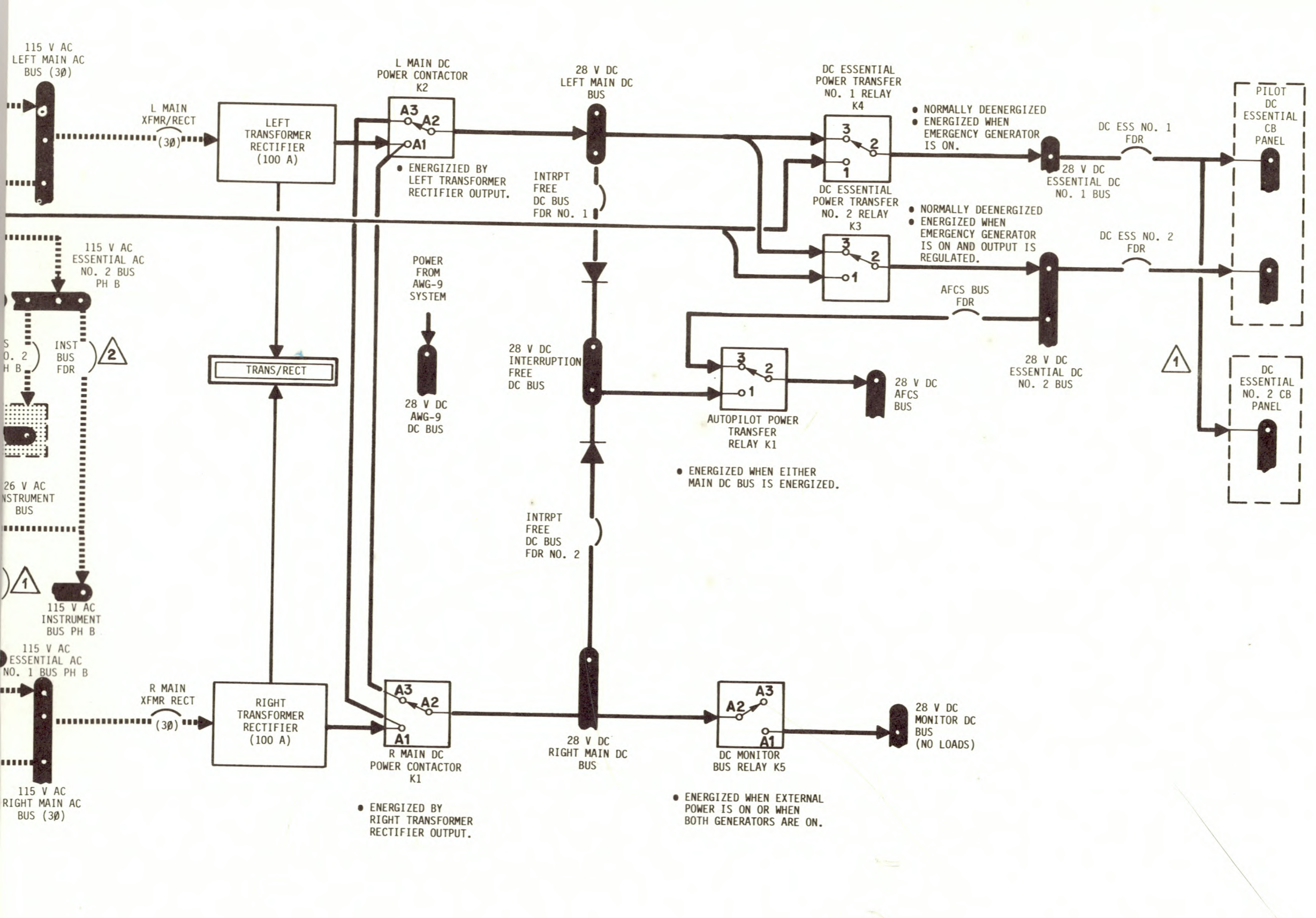

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Figure 11-2.—F-14 electrical system.

2.--F-14 electrical system.

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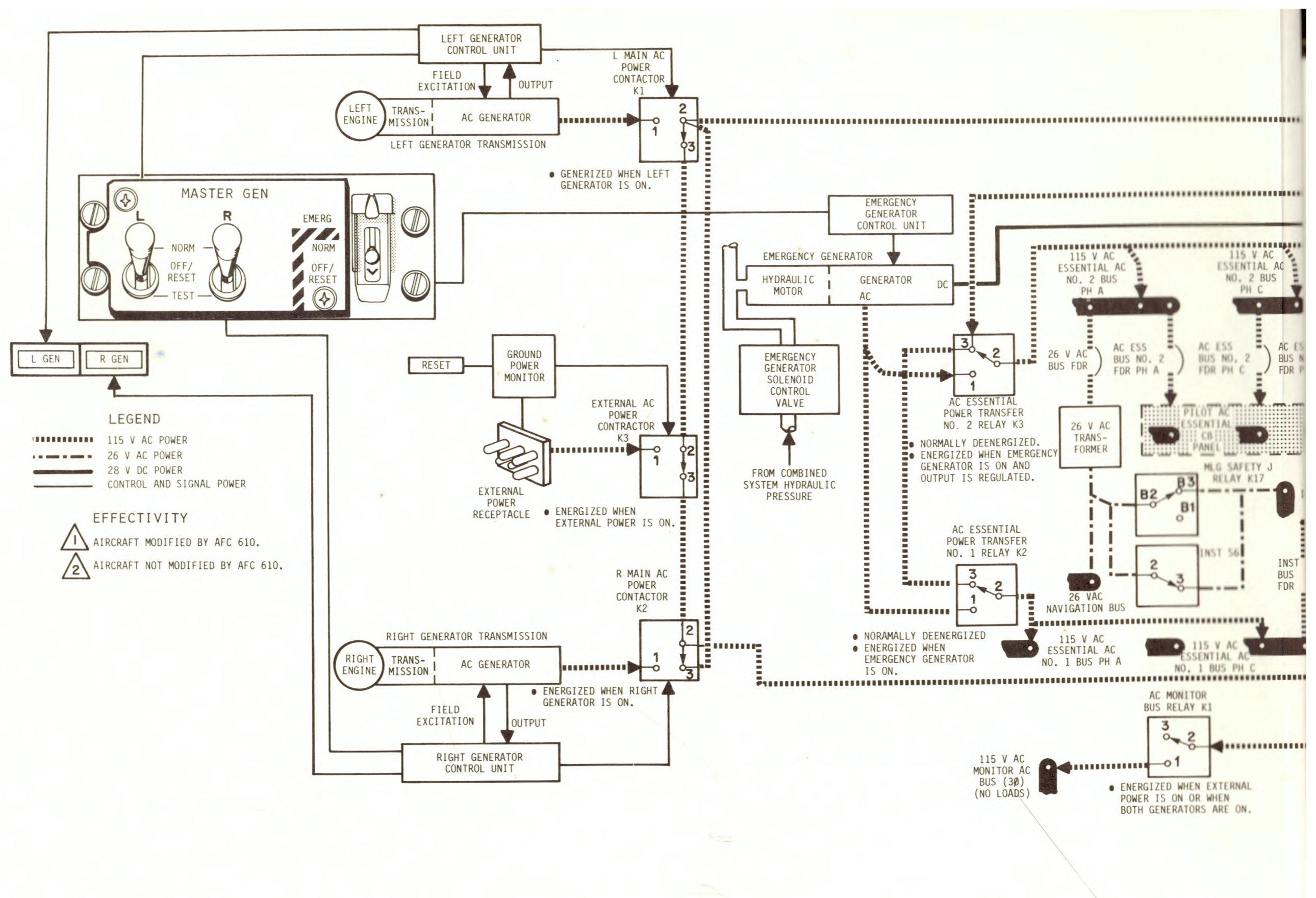
LEFT GENERATOR CONTROL UNIT
FIELD EXCITATION
OUTPUT
L MAIN AC POWER CONTACTOR K1
LEFT ENGINE
TRANS-MISSION
AC GENERATOR
LEFT GENERATOR TRANSMISSION
1
2
3
GENERIZED WHEN LEFT GENERATOR IS ON.
MASTER GEN
L
R
NORM
OFF/ RESET
TEST
EMERG
NORM
OFF/ RESET
L GEN
R GEN
LEGEND
115 V AC POWER
26 V AC POWER
28 V DC POWER
CONTROL AND SIGNAL POWER
EFFECTIVITY
1 AIRCRAFT MODIFIED BY AFC 610.
2 AIRCRAFT NOT MODIFIED BY AFC 610.
RESET
GROUND POWER MONITOR
EXTERNAL AC POWER CONTRACTOR K3
EXTERNAL POWER RECEPTACLE
ENERGIZED WHEN EXTERNAL POWER IS ON.
R MAIN AC POWER CONTACTOR K2
RIGHT GENERATOR TRANSMISSION
RIGHT ENGINE
TRANS-MISSION
AC GENERATOR
ENERGIZED WHEN RIGHT GENERATOR IS ON.
FIELD EXCITATION
OUTPUT
RIGHT GENERATOR CONTROL UNIT
EMERGENCY GENERATOR CONTROL UNIT
EMERGENCY GENERATOR
HYDRAULIC MOTOR
GENERATOR
DC
AC
EMERGENCY GENERATOR SOLENOID CONTROL VALVE
FROM COMBINED SYSTEM HYDRAULIC PRESSURE
AC ESSENTIAL POWER TRANSFER NO. 2 RELAY K3
NORMALLY DEENERGIZED.
ENERGIZED WHEN EMERGENCY GENERATOR IS ON AND OUTPUT IS REGULATED.
AC ESSENTIAL POWER TRANSFER NO. 1 RELAY K2
NORAMALLY DEENERGIZED
ENERGIZED WHEN EMERGENCY GENERATOR IS ON.
115 V AC ESSENTIAL AC NO. 2 BUS PH A
115 V AC ESSENTIAL AC NO. 2 BUS PH C
26 V AC BUS FDR
AC ESS BUS NO. 2 FDR PH A
AC ESS BUS NO. 2 FDR PH C
26 V AC TRANS-FORMER
PILOT AC ESSENTIAL CB PANEL
MLG SAFETY J RELAY K17
B1
B2
B3
INST 56
INST BUS FDR
26 VAC NAVIGATION BUS
115 V AC ESSENTIAL AC NO. 1 BUS PH A
115 V AC ESSENTIAL AC NO. 1 BUS PH C
AC MONITOR BUS RELAY K1
115 V AC MONITOR AC BUS (3Ø) (NO LOADS)
ENERGIZED WHEN EXTERNAL POWER IS ON OR WHEN BOTH GENERATORS ARE ON.

Figure 11-

GBS_FOLDOUT

GBS_FOLDOUT

CHAPTER 12

TELEVISION

Television can be defined as the transmission and reception of visual images by means of electrical signals from one point to another. All television contains the following basic elements:

1. A pickup device (transducer) to convert an optical image into an electrical signal.

2. A means of transmitting the electrical signal.

3. A reproducing device to reconvert the electrical signal into an optical image.

Pickup devices, or camera tubes, include image orthicons, image isocons, vidicons, and secondary electron conduction (SEC) tubes. Transmitting devices include coaxial lines, low- or high-power transmitters, or microwave relay links. The reproducing device is a television receiver, a television monitor, or some form of electro-optical projection system.

The first large-scale application of television was in commercial broadcasting. Technical requirements imposed on terminal equipment for commercial broadcasting are fairly well standardized by the Electronics Industries Association (EIA) (formerly the Radio-Electronics Television Manufacturers Association (RETMA)). Standardization is necessary because the objective of each television station is the same: to produce a program suitable for transmission to home receivers.

In the closed-circuit television (CCTV) industry, technical requirements vary widely from one application to another. Technical standards for closed-circuit television do not necessarily have to conform to specifications governing commercial broadcasting. Requirements for picture quality may be much lower or higher than for broadcast television. For example, when you need to read a meter at a distance, transmission standards may be lower than when the transmission involves highly detailed map information.

Another difference between commercial television and closed-circuit television is the greater variety of equipments and facilities used in closed-circuit television. Installations vary from a simple camera-monitor combination to highly complex combinations of cameras, distribution and switching equipment, and viewing monitors. Also, closed-circuit television equipment must operate under a wide variety of environmental conditions which cannot always be controlled.

As a Fire Control Technician (AQ), you must be familiar with television systems used in several different applications. These include special weapons guidance, weapon prelaunch information, and the use of television as an attack display in many of our modern aircraft.

TELEVISION FUNDAMENTALS

Television transmission of a picture from one point to another involves a process in which light, reflected from an object or scene, is converted into electrical impulses of varying magnitude. This process is accomplished by means of synchronized scanning. In synchronized scanning, the picture is examined by the camera and reproduced by the viewing monitor. This is done point-by-point and in regular pattern. The process is carried out so rapidly that the entire picture is scanned many times each second, and the eye sees it as a single complete image.

THE BASIC TELEVISION SYSTEM

The basic television system is shown in figure 12-1. It consists of a transmitter and a monitor. An image of the scene is focused on the camera pickup device. An electron beam in the device scans the optical image and produces an electrical signal which varies in amplitude with the amount of light that falls on each point of the image. A synchronizing signal is added to the electrical picture signal from the camera. The resultant composite video signal is transmitted to the display monitor.

Within the monitor, the synchronizing signal causes the beam to scan the kinescope (television picture tube) faceplate in synchronism with the camera scanning beam. The intensity of the kinescope beam is varied in accordance with the picture signal, and the image appears on the face of the kinescope.

The time required for one vertical scan of the picture in broadcast television systems in the United States is 1/60 of a second (60 hertz) or a multiple or submultiple thereof. The rate of 60 hertz per second was chosen because most commercial electrical power sources in the United States operate at a frequency of 60 Hz. Synchronization with the power frequency reduces the visible effects of hum and simplifies the problem of synchronizing film projectors with scanning.

SCANNING

The number of scanning lines determines the maximum ability of the system to resolve fine detail in the vertical direction. Also, the number of scanning lines is related to the resolution ability in the horizontal direction. Resolution is determined by the number of scanning lines because, for a given video bandwidth and frame time, horizontal resolution is inversely proportional to the number of scanning lines. Therefore, as the scanning lines are increased in number, the bandwidth of the system must also be increased in the same ratio to maintain the same resolution in the horizontal direction.

Maintaining approximately equal values of horizontal and vertical resolution is ideal. The bandwidth requirements increase as the square of the number of scanning lines. The present system of 525 lines was chosen for broadcast television as the most suitable compromise between channel width and picture resolution. This number of lines has also been found satisfactory for, and used in, many closed-circuit TV systems.

Noninterlaced Scanning

The simplest scanning method is called noninterlaced or sequential scanning (sometimes called "progressive"). This scanning method uses an electron beam which moves very rapidly from left to right on an essentially horizontal line, while it travels slowly from the top to the bottom of the picture. When the electron beam reaches the end of a line, a blanking voltage is applied which shuts off the beam. This period of time is known as the horizontal retrace period or "flyback" time. Similarly, when the beam reaches the bottom of the picture, the beam is blanked out and reappears at the top of the picture.

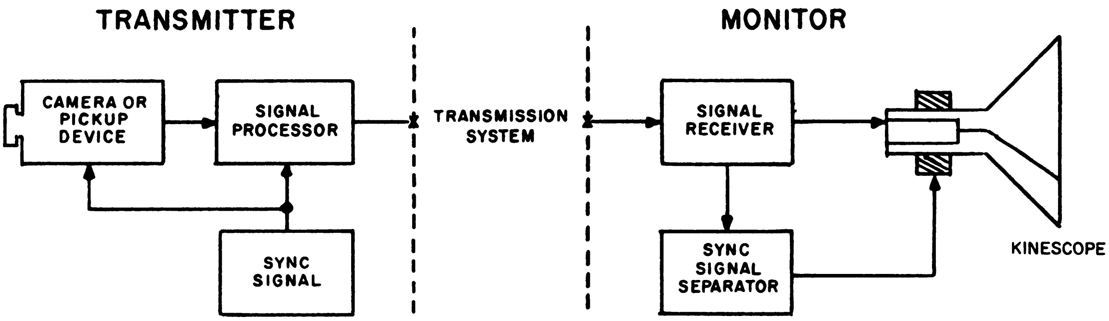

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Figure 12-1.—Basic television system.

Interlaced Scanning

An important variation of the scanning method discussed above is called interlaced scanning. It is used in broadcast television and in most closed-circuit television equipment. With interlaced scanning, it is possible to reduce the video bandwidth by a factor of two without reducing resolution or seriously increasing flicker.

In the standard two-to-one method of interlacing, alternate lines are scanned consecutively from top to bottom. Then, the remaining alternate lines are scanned. This principle is illustrated in figure 12-2, which shows interlaced scanning with 13 scanning lines. In this kind of scanning, each of the two groups of alternate lines is called a "field." The complete set of lines, consisting of two consecutive fields, is called a "frame." Interlacing is accomplished by making the total number of lines in a frame an odd integer. Thus, the number of lines in each of the two fields is an even number plus one-half line. This results in consecutive fields which are displaced in space with respect to each other by one-half of a line. Thus, interlacing of the lines is produced. In the actual method used for broadcast television and most closed-circuit television, the total number of lines is 525, the total per field is 262 1/2, the vertical scanning frequency is 60 Hz, the number of complete pictures (frames) per second is 30, and the horizontal scanning frequency is 15,750 Hz (60 × 262 1/2).

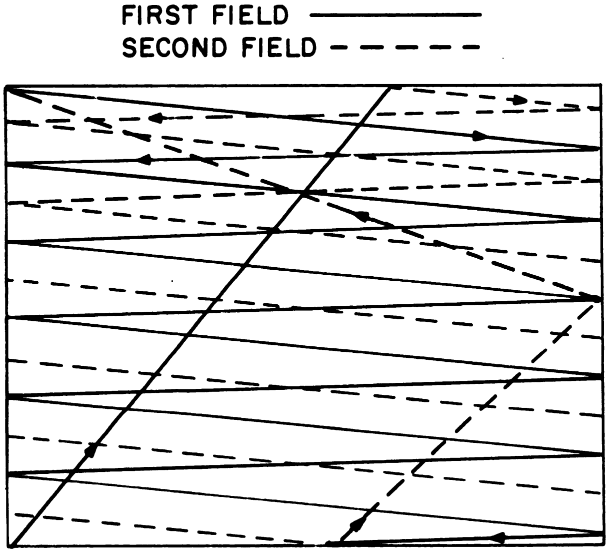

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Figure 12-2.—Interlaced scanning.

TELEVISION SIGNALS

The standard television signal consists of four elements:

1. The picture information generated during active scanning time.
2. The picture blanking pulses.
3. The picture average dc component.
4. The picture synchronizing pulses.

Picture Information

The basic part of the signal, the picture information, is a series of waves and pulses generated during active line scanning of the pickup or camera tube. A scanning line traverses (travels back and forth) the face of the pickup tube. It is modulated in amplitude in proportion to the brightness variations in the scene it is scanning. The signal produced varies in amplitude proportionally with the brightness of the scene. For commercial broadcasting, the amplitude variations are such that the maximum video amplitude produces black, and the minimum video amplitude produces white. Ordinarily the maximum and minimum video amplitude values represent 75 percent and 15 percent of the maximum carrier voltage, respectively.

Picture Blanking Pulses

In order to prevent undesirable signals from entering the picture during retrace time, blanking pulses are applied to the scanning beams in both the camera tube and the receiver kinescope. Camera blanking pulses are used only in the pickup device. They serve only to close the scanning aperture on the camera tube during retrace periods and never actually appear in the final signal sent to the receiver. In some systems, the same pulse that triggers the scanning circuit and blanks the kinescope also closes the camera scanning aperture.

The function of the kinescope blanking pulses is to suppress the scanning beam in the kinescope during both vertical and horizontal retrace time. They are simple rectangular pulses, somewhat wider than the corresponding camera blanking pulses. They have a duration slightly longer than the actual retrace periods in order to trim up the edges of the picture and provide a clean noise-free period during retrace. The complete video signal shown in figure 12-3 contains pulses for the removal of visible lines during horizontal retrace periods only. The horizontal pulses recur at intervals of 1/15,750 of a second. At the bottom of the picture they are replaced by vertical blanking pulses which are similar to the horizontal pulses, except they are of much longer duration (approximately 15 scanning lines) and have a periodic recurrence of 1/60 of a second.

Note that the blanking pulses (and synchronizing pulses) are added at a relatively high-level point in the transmitter and are, therefore, considered to be noise-free. The importance of noise-free blanking and synchronizing pulses should not be underestimated. They determine the stability of the viewed picture or the degree to which a picture will remain locked-in on a kinescope even under the most adverse transmission conditions. This point is especially important when considering the use of television for closed-circuit applications. The extreme environmental conditions which may be encountered can seriously degrade the picture signal, making it difficult to synchronize or lock-in a picture unless the original blanking-to-picture and signal-to-noise ratios are high.

Picture Average dc Component

If a television picture is to be transmitted successfully with the necessary fidelity, it needs the dc component of the picture signal. This component is a result of slow changes in light intensity. The loss of the dc component occurs in ac or capacitive coupling circuits and is evidenced by the picture signal tending to adjust itself about its own ac axis. The dc component is returned to the video signal by means of a dc restorer or inserter circuit.

Synchronizing

Synchronization of the scanning beams in the camera and the receiver must be exact at all times in order to provide a viewable picture. To accomplish this, synchronizing information is provided in the form of electrical pulses in the retrace intervals between successive lines and between successive pictures (see figure 12-3). The retrace periods (which are as short as circuit considerations permit) are in areas in which synchronization pulses may be inserted without interfering with the picture.

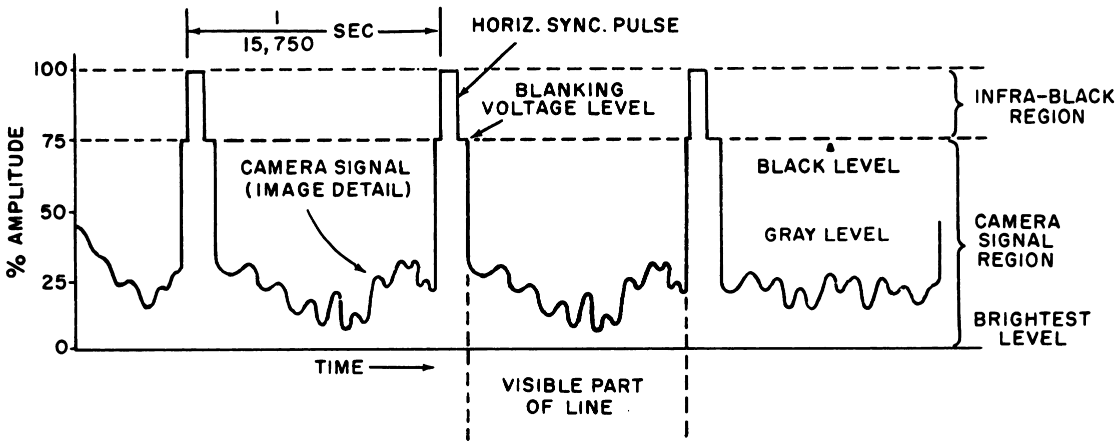

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Figure 12-3.—The complete video signal for three scanned lines.

Synchronizing pulses are generated at the program origin end of the television system in the equipment that controls the timing of the scanning beam in the pickup tube. They become a part of the complete signal which is transmitted to the receiver or monitor. In this manner, scanning operations in both ends of the television system are always in step with each other. In general, synchronizing signals should provide positive synchronization of both horizontal and vertical sweep circuits. They should be separable by simple electronic circuits to recover the vertical and horizontal components of the composite sync signal. They should be able to be combined simply with the picture and blanking signals to produce a standard composite television signal.

Most television systems produce synchronizing information which conforms to the basic requirements of synchronization. Figure 12-3 shows how the synchronizing signal waveform is added to the picture information and blanking signals to form a complete composite picture signal ready to be transmitted. Note that the duration of the horizontal sync pulses is considerably shorter than that of the blanking pulses. Vertical sync pulses are rectangular, but they are of much shorter duration than the horizontal pulses. Thus, they provide the necessary means for frequency discrimination.

Synchronization presents a difficult problem as the largest number of failures occurs as a result of the loss of proper interlacing. Discrepancies in either timing or amplitude of the vertical scanning of alternate fields cause displacement in space of the interlaced fields. The result is nonuniform spacing of the scanning lines. This reduces the vertical resolution and makes the line structure of the picture visible at normal viewing distance. The effect is usually called "pairing."

Another series of pulses is added before and after the vertical sync pulses to prevent the pairing problem and maintain continuous horizontal synchronizing information throughout the vertical synchronization and blanking interval. These are "equalizing" pulses (figure 12-4). The time between the last horizontal sync pulse and the first equalizing pulse changes from a full horizontal line interval to one-half of a horizontal line interval every other field. This is caused by the ratio between 15,750 Hz and 60 Hz. The ratio produces the necessary difference between fields to provide interlaced scanning. Since the horizontal oscillator is adjusted to the frequency of the horizontal sync pulses, it is triggered only by every other equalizing pulse or serration of the vertical sync pulse.

OTHER SYSTEMS

Although commercial broadcasting and many closed-circuit installations adhere closely to the previously mentioned EIA standards, some noncommercial as well as closed-circuit installations use synchronizing signal specifications which are

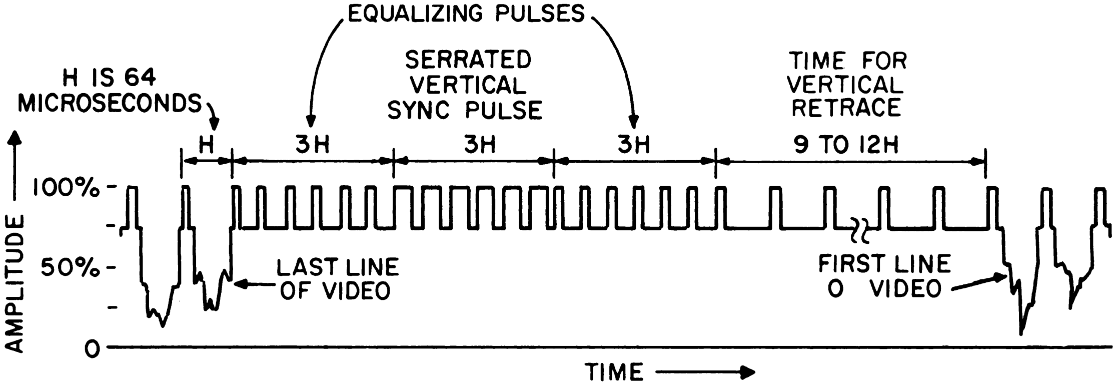

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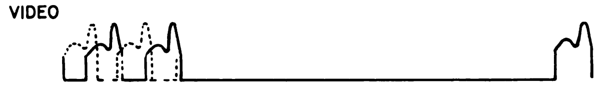
Figure 12-4.—Vertical synchronizing and equalizing pulses.

considerably less rigorous. The television systems which are discussed fall into four general categories.

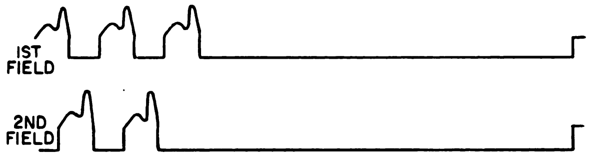
Random Interlace, No Special Sync Pulses

The random interlace is the simplest television method. It provides no special sync pulses and no fixed relationship between the horizontal and vertical scanning raster. "Lock-in" or synchronization information at the receiver or monitor is obtained from the horizontal and vertical blanking pulses contained in the video signal as shown in figure 12-5(A). Usually at the camera control location, sufficient blanking signal or "setup" is added to the video signal to provide an adequately long and steep transition at both vertical and horizontal frequencies to provide lock-in.



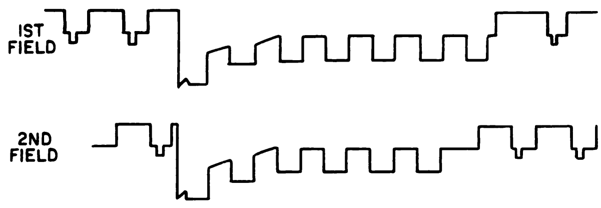
RANDOM INTERLACE. NO LOCK-IN BETWEEN VERTICAL AND HORIZONTAL FREQUENCIES.
RANDOM POSITIONING OF HORIZONTAL WITH RESPECT TO VERTICAL.

(A)



HORIZONTAL AND VERTICAL SCANNING LOCK-IN. NO SEPARATE SYNCHRONIZING PULSES.

(B)



HORIZONTAL AND VERTICAL SCANNING LOCK-IN, WITH MODIFIED SYNCHRONIZING PULSES ADDED.

(C)

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Figure 12-5.—Nonstandardized television waveforms (positive picture phase).

Some receivers and monitors may have difficulty, however, in synchronizing with this information. Electrical noise is a possible condition when the camera and viewing device are separated by a great distance. The lock-in of such a signal becomes extremely difficult. Note in figure 12-5(A) that there is no horizontal sync signal during vertical blanking time. The horizontal frequency circuit in the monitor, even though it has some tendency to keep on the correct frequency, will be essentially free-running during this period. This may not be detrimental during blanking or retrace time. However, when the horizontal sync information returns, the receiver horizontal circuits may have trouble synchronizing to the new information.

The most undesirable characteristic of this television system is insufficient resolution caused by lack of interlace. Good interlace is not possible because an absolute frequency relationship between the horizontal and vertical frequencies is lacking. The nominal vertical frequency is usually 60 Hz (lock-in to the 60-Hz power line), while the horizontal frequency (usually established by a free-running oscillator) is nominally 15.75 kHz. Thus, there is no direct relationship between the two frequencies (horizontal frequency should be an odd multiple of one-half the field rate) as required for satisfactory interlace. The advantages of such a system are reduced cost and greater simplicity of circuits. However, marginal resolution capabilities, incompatibility, marginal stability, and general reduction of system performance limit its application and use.

Odd-Line Interlace, No Special Sync Pulses

The odd-line interlace system has a distinct advantage over the previous system. A definite relationship exists between the horizontal scan frequency and the vertical field rate. This system, whose waveform is shown in figure 12-5(B), can effectively use the 2:1 odd-line interlace technique. Therefore, it provides a considerable improvement in the resolution capabilities of the system. In theory, the vertical resolution should be double that of the previous system. In practice, however, the improvement in resolution is somewhat less since it is difficult to obtain perfect interlace (no pairing).

Like the random interlace, this system does not provide a special synchronizing signal, and it is subject to the same synchronizing or lock-in limitations as were discussed previously. These limitations become an important problem in the more elaborate installations where a series of cameras and monitors separated by wide distances might be used. For this reason, installations using these systems are usually limited to smaller, less complex applications where stability and reliability may not be an important factor.

Odd-Line Interlace, Modified Sync Pulses

The odd-line interlace method provides further advantages over the previous two systems, but it has a considerable number of limitations when compared with the EIA system. In this system, a form of special synchronizing signal has been added to the video waveform (figure 12-5(C)). Note that the synchronizing signal has been added to the tip of each horizontal blanking pulse. The sync pulses also continue through the vertical blanking interval. They provide synchronizing information for the monitor horizontal frequency-locking circuits at all times. These circuits are therefore no longer free-running during the vertical blanking interval. Addition of the special sync pulse information greatly improves the lock-in ability of the composite video signal under adverse conditions of noise and spurious signals.

Slow-Speed Scan

A television system which is being used more frequently uses the slow-speed scan technique. This technique represents a radical departure from nominal scanning standards. It permits a scene, which contains a limited amount of action or movement and a great deal of redundancy, to be picked up and transmitted successfully from one location to another. It affords fair resolution and fidelity in signals transmitted over relatively economical narrow-band transmission facilities. For example, a "slow-speed" camera located in a bank, a message center, or a newspaper office can scan printed information and transmit it to a distant location over ordinary telephone-line facilities. Some methods are able to transmit pictures having more action, such as a person talking, with reasonable clarity. Such methods, however, require somewhat greater bandwidth.

Most slow-speed scan systems use a much slower scanning rate, with a correspondingly narrower bandwidth, than present telecasting standards. Broadcasting systems transmit a picture every 1/30 of a second, with a 4-MHz bandwidth. Slow-scan systems transmit a picture in 1/10 of a second to 2 seconds, with a video bandwidth ranging from approximately 250 kHz to as low as 500 Hz.

Slow-speed scan systems are practical where time is available for transmission. For example, the information contained in a five-minute commercial television program requires several hours of time to be transmitted with comparable detail by the average slow-speed scanning technique. The advantages of the slow-speed scanning system are greatly simplified equipment and relatively inexpensive transmission facilities, as compared to the complex relay systems required for broadcast television. The disadvantages are that the scene content is limited to relatively immobile objects, resolution is marginal, and the system is incompatible with standard television systems. Rather complex scan conversion equipment is required to make the two systems compatible. Except for certain special applications, slow-speed scan systems are inferior in performance and cannot be used successfully where a high degree of resolution and detail is required.

CAMERA TUBES

The type of camera tube used is determined by the intended use of the camera and the amount of available illumination. The amount of light required by a camera tube is rated in candelas. The minimum number of candelas required by a camera tube is a measure of the tube's sensitivity. The following types of camera tubes are used in modern CCTV systems.

VIDICON TUBE

The vidicon camera tube (figure 12-6) has a transparent conductive coating, called the signal electrode, on the inner surface of the faceplate; a layer of photoconductive material deposited on the signal electrode; an accelerating anode; a focusing coil; and a cathode emitter for producing a beam of electrons. Associated with the vidicon tube are the alignment coil, the focus coil, and the deflection coils.

The alignment coil produces a magnetic field that is variable in both magnitude and direction and is used to adjust the direction of the electron beam so that it is parallel to the field of the focus coil. Control of the alignment coil current is accomplished in the control unit.

The focus coil surrounds the vidicon tube and establishes a magnetic field along the axis of the tube. It is connected between the + 300-volt and the + 150-volt power supplies through a resistor located in the rotatable section of the base unit.

The vertical and horizontal deflection coils are excited by linear sawtooth currents from the control unit. These currents produce the field that causes the beam to scan the photosensitive layer.

The beam of electrons is directed toward the layer of photoconductive material (on the cathode side of the signal electrode) at a medium velocity because of the relatively low accelerating potential between the cathode and the accelerating electrode. A sharp beam is formed by the electrostatic field of the focus electrode and the axial magnetic field of the focus coil surrounding the tube. The electron beam is deflected by the deflection coil in such a way as to scan the photoconductive layer. When no light is permitted to reach this layer, its resistivity is extremely high. One side of the layer is maintained at a small positive potential of 0 to 70 volts by direct contact with the signal electrode.

When light from the scene being televised passes through the faceplate and is focused on the photoconductive layer, the resistivity of this material (which has been extremely high) is reduced in proportion to the amount of light

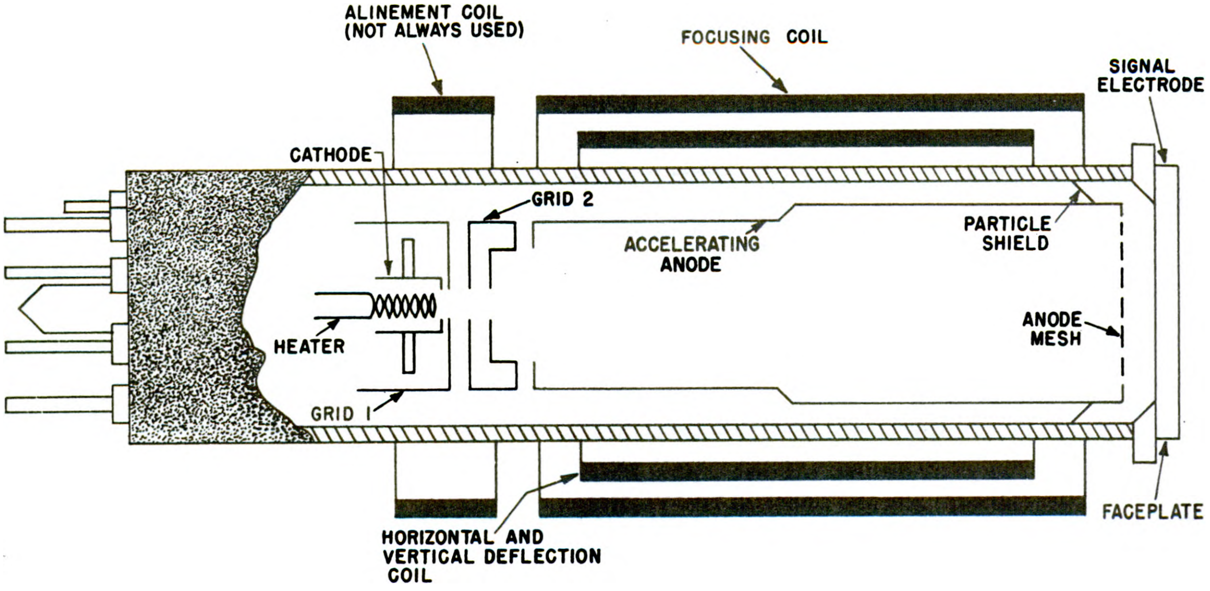

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Figure 12-6.—Structure of vidicon.

reaching it. Because the potential gradient between adjacent elements in the photoconductive layer is much less than the potential gradient between opposite sides of the layer, electrons from the beam side of the layer leak by conduction to the other side between scans of the electron beam. Consequently, the potential of each element on the beam side approaches the potential of the signal electrode side, and it reaches a value that varies with the amount of light falling on the element. On the next scan, the electron stream replaces a number of electrons on each element just sufficient to return it to the potential of the cathode. Because each element is effectively a small capacitor, a capacitive current is produced in the signal-electrode circuit that corresponds to the electrons deposited as the element is scanned. When these electrons flow through the load resistor in the signal-electrode circuit, a voltage, which becomes the video signal, is produced.

PLUMBICON

The plumbicon tube is similar in appearance and operation to the vidicon. It has several advantages over the vidicon. The plumbicon tube has a more rapid response and produces high quality pictures at lower light levels. Because of its small size and low power consumption, the plumbicon tube is well suited for use in transistorized TV cameras. Its simplicity and spectral response to primary colors make it particularly useful in color cameras.

A unique feature of the plumbicon is that its color response can be varied by the manufacturer. It is therefore available with spectral responses for each of the primary colors. The color response of each tube is identified by the letter R (red), G (green), or B (blue) following its basic number. For example, a plumbicon for a green channel may be designated 55875G.

Figure 12-7 provides a simplified diagram of a plumbicon target. The glass faceplate, as shown in (A) of figure 12-7, has its inner surface coated with tin dioxide. This thin, transparent layer is the signal plate of the target. The tin dioxide itself is a strong N-type semiconductor. Two layers of lead oxide are deposited on the scanning side of the target. The first of these two layers is almost pure lead oxide, an intrinsic semiconductor. The second layer of lead oxide is doped to form a P-type semiconductor. As shown in (B) of figure 12-7, the three layers form a P-I-N junction.

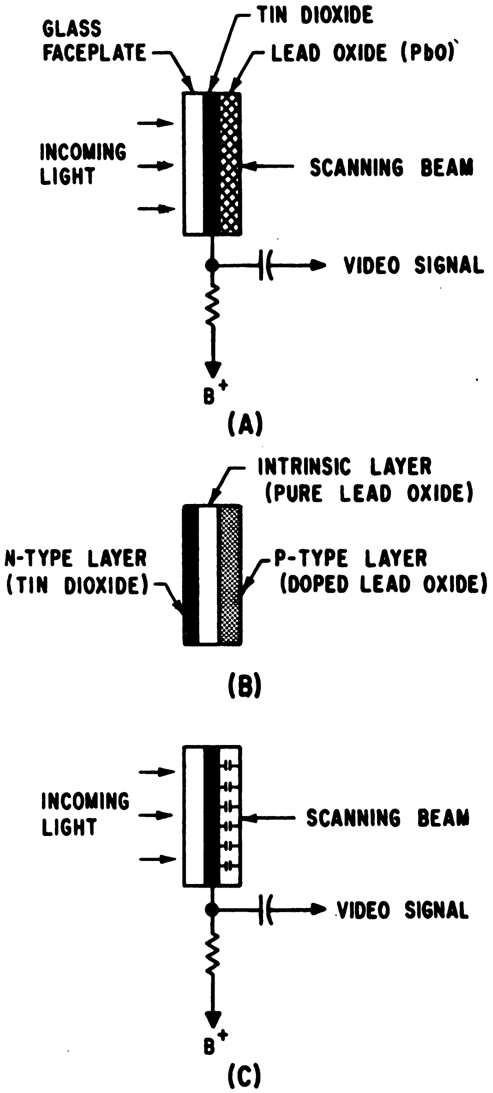

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Figure 12-7.—Plumbicon target.

Light from the televised scene passes through the layer of tin dioxide and is focused on the photoconductive lead oxide. Note in (C) of figure 12-7 that each picture element charge acts like a capacitor whose positive plate faces the scanning beam. The target signal plate forms the negative plate. As the low-velocity scanning beam strikes each charged element, it releases electrons which neutralize the "capacitors."

IMAGE ORTHICON

The image orthicon (figure 12-8) is an ultra-sensitive television camera pickup tube. The tube requires only 8 to 40 candelas for light and is used in modern conventional and closed-circuit television systems. When this tube is used, a light image from the subject (arrow at extreme left) is picked up by the camera lens and focused on the light-sensitive face of the tube, releasing electrons from each of the thousands of tiny globules in proportion to the intensity of the light striking it.

These electrons are directed on parallel courses from the back of the tube face to the target, from which each striking electron liberates several more electrons, leaving a pattern of proportionate positive charges on the front of the target. When the back of the target is scanned by the beam from the electron gun in the base of the tube, enough electrons are deposited at each point to neutralize the positive charges. The rest of the beam returns, as shown in figure 12-8, to a series of electron multiplier stages or dynodes surrounding the gun.

Each dynode is a metallic disk with openings similar to a pinwheel and operates at a positive potential of 200 to 300 volts greater than the preceding dynode. Multiplication occurs through secondary emission at each dynode. If five dynode stages are used, each having a gain of 4, a gain of 4 × 4 × 4 × 4 × 4 or approximately 1,000, is realized in the multiplier section. Considering the gain of 5 in the image section, the overall gain of the image orthicon is 5,000, which allows this particular pickup tube to operate with relatively less light than the plumbicon or vidicon. The electrons from the last dynode are routed through a signal-developing resistor to an extremely high B+ voltage. The output signal is then coupled to the first stage of video amplification.

SECONDARY ELECTRON CONDUCTION (SEC) TUBE

This is a vidicon-like tube with a special target that uses secondary electron conduction (SEC).

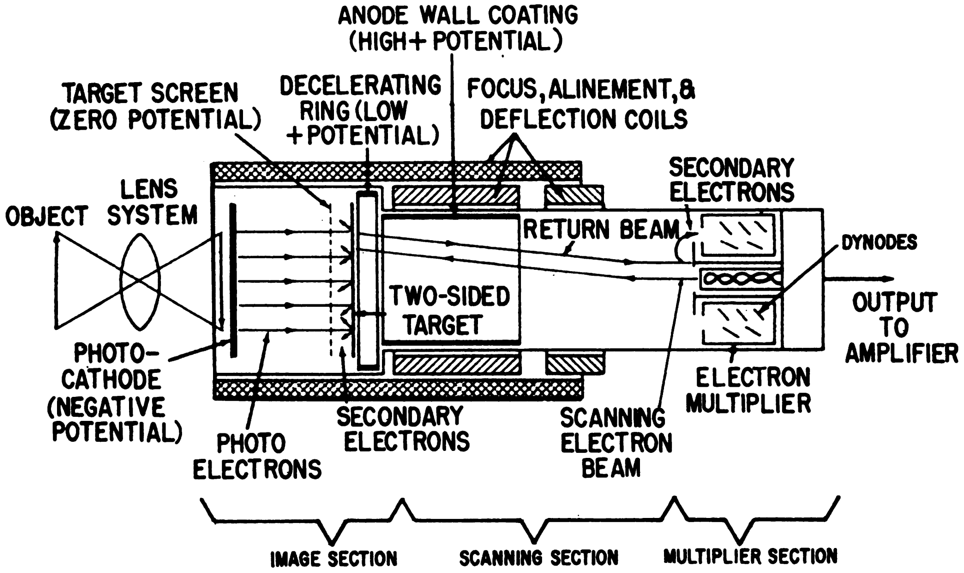

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Figure 12-8.—Structure of image orthicon.

In this tube, light is focused on the photocathode which emits electrons into the tube. These electrons are focused to form an image of electron streams which strike the SEC target. The electrons are accelerated to approximately 10,000 electron volts by the time they strike the target. The SEC target intercepts these streams of electrons, and a great number of secondary electrons from each electron striking the target are emitted and stored (figure 12-9). The photoelectrons possess sufficient energy to penetrate the thin, metallic signal and support plate. As they travel through the porous potassium-chloride layer, many secondary electrons are emitted as the beam strikes the interlinked particles. These secondary electrons either escape to the positive collector screen or they travel through the spaces of the porous layer to the positive collector plate. This loss of electrons produces a positive charge on the scanned side of the target. Several hundred secondary electrons are emitted for each incident electron, producing a substantial gain at the target.

The video signal is developed from the target by the scanning beam discharging the positively charged areas of the target in the same manner as in a vidicon tube. This charging current, flowing out of the signal plate connection, is then amplified by an external amplifier.

The SEC tube has applications in extremely low-light nighttime military TV systems where a high internal amplification and a fast speed or response to moving images are important.

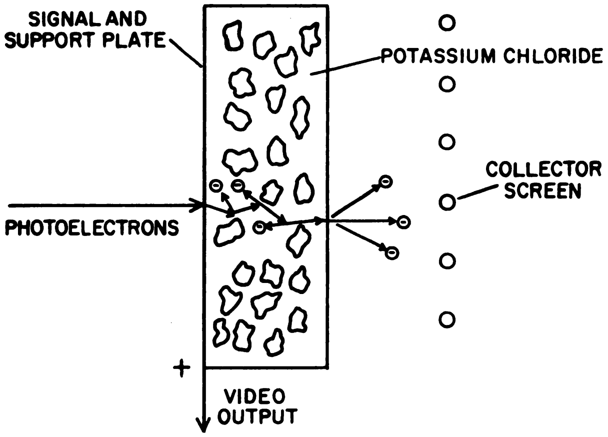

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Figure 12-9.—SEC camera tube target operation.

CAMERA CIRCUITS

The purpose of camera amplifier circuits is to amplify the extremely low output signal from the camera tube. The video signals must be increased in amplitude to overcome tube noise and random circuit noise and hum that may be injected into the video output.

The camera circuits are carefully designed to amplify high- and low-frequency signals equally. The output of the camera tube (figure 12-10) must be as large as possible. The output circuit contains high resistance, providing good gain at low frequencies but low gain at high frequencies. Because a video signal contains both high- and low-frequency components, the video stages are designed to amplify more at some frequencies than at others.

BLOCK DIAGRAM ANALYSIS

Video preamplifier Q1/Q2 (figure 12-10) serves as a "peaker" circuit because it provides greater amplification to the higher video frequencies. Note that the resultant frequency response curve at the output of Q1/Q2 is reasonably flat over a wide band of video frequencies.

The video signal from Q1/Q2 is routed through emitter follower Q3 and developed across a resistor in the camera control unit. Emitter follower Q3 is used to match the output impedance of the camera unit to the input impedance of the control unit.

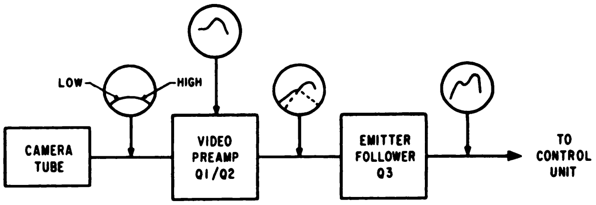

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Figure 12-10.—Typical camera unit block diagram.

CAMERA CIRCUIT ANALYSIS

Figure 12-11 illustrates the circuits in a typical camera unit. The vidicon is represented schematically by V1. The elements in a vidicon tube have functions similar to those in an ordinary electron tube; however, the vidicon tube terminology differs somewhat because the control grid is called the beam control, and the plate the target control.

When the camera circuit is operating, the video signal leaves the vidicon through pin C and is developed across R3. A variable dc focusing voltage is applied to pin 6 of V1 via decoupling network R4 and C2. A fixed positive accelerating voltage is applied from pin 13 of J1, through the contacts of K1, to pin 5 of V1. K1 is normally energized while the camera is operating. (K1 is shown energized.) Vertical blanking pulses and a variable beam control bias are applied from pin 1 of J1 to pin 2 of V1. Pulses from the horizontal deflection yoke are coupled through S2 (shown in normal position), differentiated by C1 and R2, clipped by CR1 and R1, and applied as sharp positive horizontal blanking pulses to the cathode of V1.

Video output from V1 is coupled through C3 to the base of Q1. Q1 and Q2 comprise a compound-connected transistor circuit known as a Darlington Amplifier. This type of circuit was selected for use as the preamplifier stage because

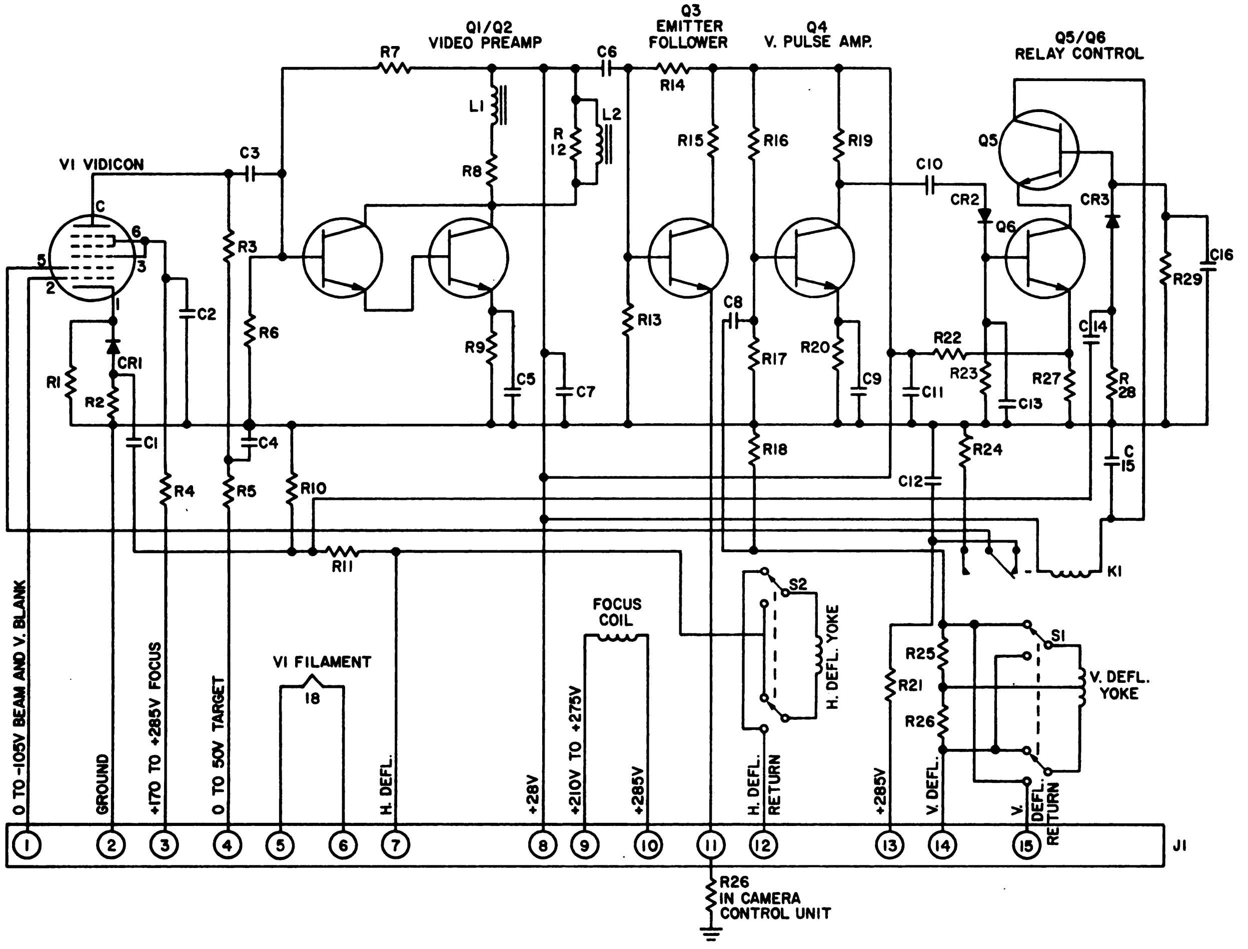

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Figure 12-11.—Typical camera circuit.

it has high input impedance, very high current gain, and excellent frequency response. Forward bias for the stage is provided by voltage divider components R6 and R7. R9 and C5 are primarily intended for temperature compensation. The amplified video output from the collector of Q2 is developed across R8 and L1 (a shunt-speaking circuit), and coupled through R12 and L2 (a series-peaking circuit) to the base of emitter follower Q3. This stage provides an impedance match to allow coupling of the video via coaxial cable to emitter load resistor R26 in the camera control unit.

Vidicon Protection Circuitry

Q4, Q5, and Q6 are used in circuitry designed for vidicon tube protection. Recall from your knowledge of cathode-ray tubes, that it is undesirable to allow the electron beam to remain too long on the same spot on the CRT screen. If this occurs or the beam retraces the same line too often, the phosphor coating on the CRT screen will "burn." A vidicon target is comparable to a CRT screen, because if the vertical and horizontal sweep signals are not present, the vidicon target could become permanently damaged.

Pulsed amplifier Q4 serves to amplify a sampling of the vertical sweep signal which enters the camera on pin 14 of J1. This signal is attenuated by R26 and R25 and coupled through C8 to the base of Q4. After being amplified by Q4, the signal is coupled through C10, rectified by CR2, and filtered by R23 and C13. The resultant positive dc voltage is used as forward bias for Q6. Note Q6 is connected in series with Q5, forming (in terms of digital computers) an AND gate. To allow current to flow through both Q5 and Q6, forward bias for Q5 must also be provided.

Forward bias for Q5 is developed, logically enough, by action of the horizontal sweep signal, which consists of pulses at 15,750 Hz. This signal enters the camera unit through pin 7 of J1. The pulses are attenuated by R11, coupled through C14 to the anode of CR3, and then rectified. R29 and C16 filter the resultant dc, which is used as forward bias for Q5.

Remember that Q6 is forward biased only as long as a vertical deflection signal is present in the camera unit, and Q5 is forward biased only as long as a horizontal deflection signal is present. Therefore, BOTH the vertical and horizontal deflection signals must be present for current to flow through Q5 and Q6.

Note that the coil of current-sensitive relay K1 is in the collector circuit of Q5. If Q5 and Q6 are conducting, K1 is energized. Look at pin 13 of J1. A +285 volts dc is routed from pin 13 through R21 and the energized contacts of K1 to pin 5 of the vidicon. If the +285 volts dc is NOT present, the vidicon is cut off. If K1 deenergizes, a ground is applied through R24 to pin 5 of the vidicon tube, assuring that the tube is cut off.

To summarize, if either the horizontal or vertical deflection signal is not present, K1 will deenergize, causing the vidicon to cut off. This provision, of course, serves to protect the vidicon target from being "burned" if sweep signals are lost.

Special Effects

Switches S1 and S2, connected across the vertical and horizontal deflection yokes, respectively, are used to initiate special video effects. Closing S1 causes the image to invert because the direction of current flow is reversed through the vertical yoke. Similarly, closing S2 results in a mirror image because current now flows in the opposite direction through the horizontal yoke.

COLOR CAMERAS

The camera unit used for color pickup is similar to the black and white camera previously discussed. In the color camera, the camera unit (figure 12-12) has three pickup tubes (one for each

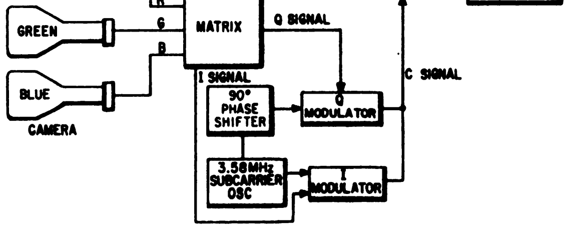

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Figure 12-12.—Color TV transmitter block diagram.

of the primary colors). Filters and mirrors are used to direct the right color of light to its respective pickup tube. The output of the camera unit provides a red, green, and blue video signal to the matrix system (a circuit which proportions the primary signals to produce the correct brightness and chrominance colors). The three primary colors are identified as R for red, G for green, and B for blue.

The matrix section is essentially a resistive voltage-divider circuit that proportions the primary color signals, as required, to produce the brightness and chrominance signals. With red, green, and blue color video voltages as inputs, the three video signal output combinations formed are the following:

1. A luminance signal, designated the Y signal, which contains the brightness variations of the picture information.
2. A color video signal, designated the Q signal, which corresponds to either green or purple picture information.
3. A color video signal, designated the I signal, which corresponds to either orange or cyan picture information.

The I and Q signals together contain the color information for the chrominance (hue and saturation) signal.

Additional information concerning the color video signal and its transmission will be presented later in this chapter as part of the coverage of the composite video signal.

COMPOSITE VIDEO

The composite video signal contains all the information needed to reproduce the picture. Its contents include the video from the camera unit, synchronizing pulses to synchronize the transmitter signal with the receiver/monitor, and blanking pulses to obliterate the retrace signals from the picture tube. The video signal is combined with the blanking pulse (figure 12-13), and the sync pulse is placed on top of the blanking pulse.

In the composite video signal, successive values of voltage and current amplitudes are shown against values of time during the scanning of three horizontal lines. During the time when blanking and sync pulses are being transmitted, no video appears. The overall signal amplitude is divided into two parts: the lower 75 percent is for video, and the upper 25 percent is devoted to synchronizing pulses. Standardization is necessary to ensure the transmitted signal is suitable for all receivers/monitors.

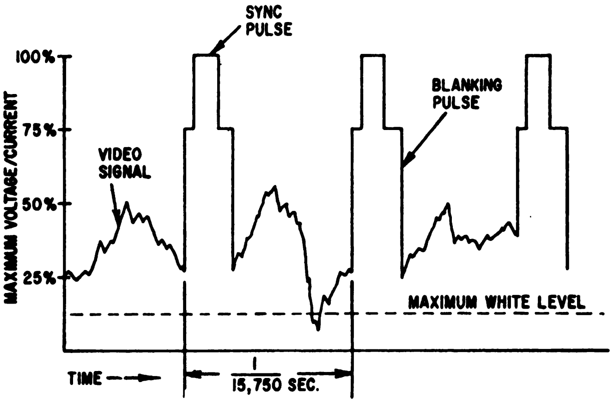

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Figure 12-13.—Composite video signal.

The lowest amplitudes correspond to the whitest parts of the picture. The picture becomes blacker as amplitude increases toward 75 percent. This standard of transmission is called "negative transmission," which is defined as decreasing signal amplitude for decreasing light intensities.

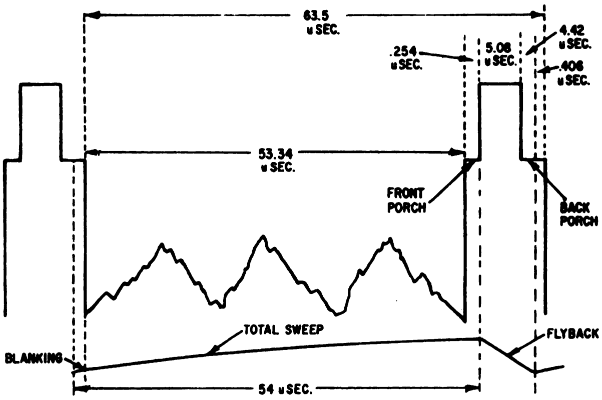

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Figure 12-14.—Composite video time allocations.

As the level reaches 75 percent, the grid becomes negative, cutting off the picture tube. The absence of light establishes the blackest level, which is the case when the blanking level occurs.

Details of the horizontal blanking and sync pulse are shown in figure 12-14. The interval of the complete scan is 63.5 microseconds since the horizontal frequency is 15,750 Hz. The horizontal blanking pulse is 10.16 microseconds, or about 16 percent of total sweep. The sync pulse, superimposed on the pedestal, occupies 5.08 microseconds or one-half the blanking time.

The part of the pedestal just before the sync pulse (0.254 microsecond) is called the "front porch"; the portion following the sync pulse (4.826 microseconds) is called the "back porch." The front porch blanks the right side of the picture screen just before the sync pulse begins. Flyback occurs with the leading edge of the sync pulse and continues for 4.42 microseconds of the back porch. The next sweep starts, but the left side of the screen is blanked for 0.406 microsecond of the starting sweep. This action strives to maintain a straight left edge.

The vertical blanking pulse blanks the picture during retrace time when the electron beam has completed one field and is returned to the top ready to start the next field. Immediately following the last active line, the video signal is brought up to the black level by the vertical retrace.

So far in the discussion, little has been said about the special form of the combined synchronizing pulses. The form and the timing of the synchronizing pulses are such that the horizontal and vertical oscillators are triggered at exactly the right instant to keep the sweep in the camera tube and the sweep in the picture tube locked in step. Because the horizontal oscillator must be triggered during the vertical sync pulse (to prevent the horizontal oscillator from drifting out of control), the vertical pulse is serrated, as shown in figure 12-15; that is, the vertical pulse is chopped into

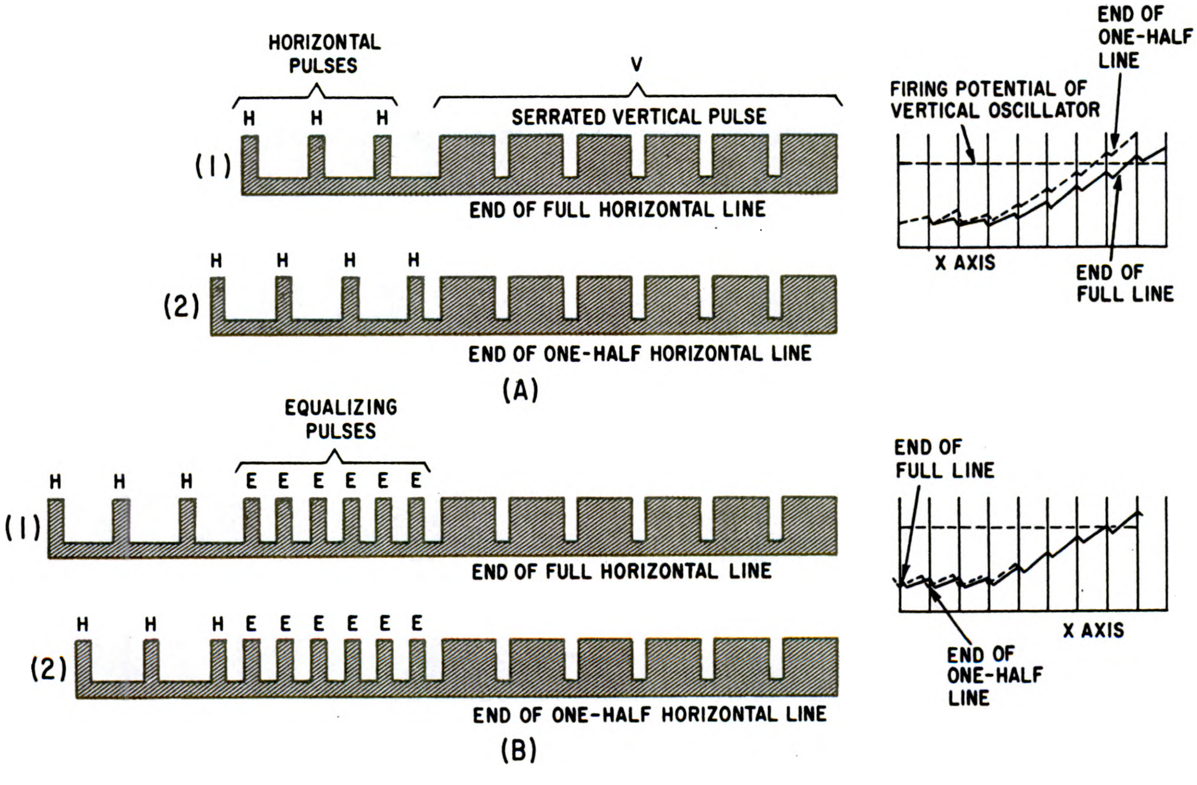

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Figure 12-15.—Synchronizing pulse forms. (A) Without equalizing pulses; (B) with equalizing pulses.

six pieces. The fluctuations resulting from serrations do not affect the operation of the vertical oscillator, but serve only to keep the horizontal oscillator properly triggered.

In addition to the serrations in the vertical pulse, equalizing pulses are necessary before and after each vertical pulse. The necessity for equalizing pulses, labeled E in figure 12-15(B), may be explained as follows:

First, assume that no equalizing pulses are used, as in figure 12-15(A). If the vertical pulse is inserted at the end of the field, which occurs simultaneously with the end of a full horizontal line (part (1)), the firing potential of the vertical oscillator is reached at the correct time to produce the desired interlaced scan.

If the vertical pulse is inserted at the end of a field, which occurs simultaneously with the end of a half horizontal line (part (2)), the firing potential of the vertical oscillator is reached too early. This is because the slight charge on the capacitor in the triggering circuit of the vertical oscillator (due to each horizontal pulse) does not have time to leak off before the vertical pulse arrives. The residual voltage across this capacitor, plus the voltage due to the vertical pulse, causes the vertical oscillator to fire too soon.

Second, the situation is corrected, as shown in figure 12-15(B), by the use of equalizing pulses. The buildup of the vertical pulse cross the capacitor now begins at the same point, whether the vertical pulse arrives at the end of a full line or at the end of a half-line. In other words, the equalizing pulses cause the potential on the capacitor to be at the same level (at the same time the vertical pulse arrives) whether the vertical pulse occurs at the end of a half line or at the end of a full line. Although not shown in the figure, equalizing pulses are also used after the vertical pulses.

To get a better idea of the form of sync pulses, study figure 12-16. You can see that a number of horizontal scans are lost during the vertical flyback time.

CONTROL UNIT

Sync generators in the control unit function to provide reference signals to keep the scanning signals in the monitor in step with those in the camera. Another function of the control unit is to maintain a stable phase relationship between the vertical and horizontal scanning signals. If the phase relationship between these signals is allowed to vary, the 2:1 interlaced scan will not be stable. To obtain the required phase lock, both the

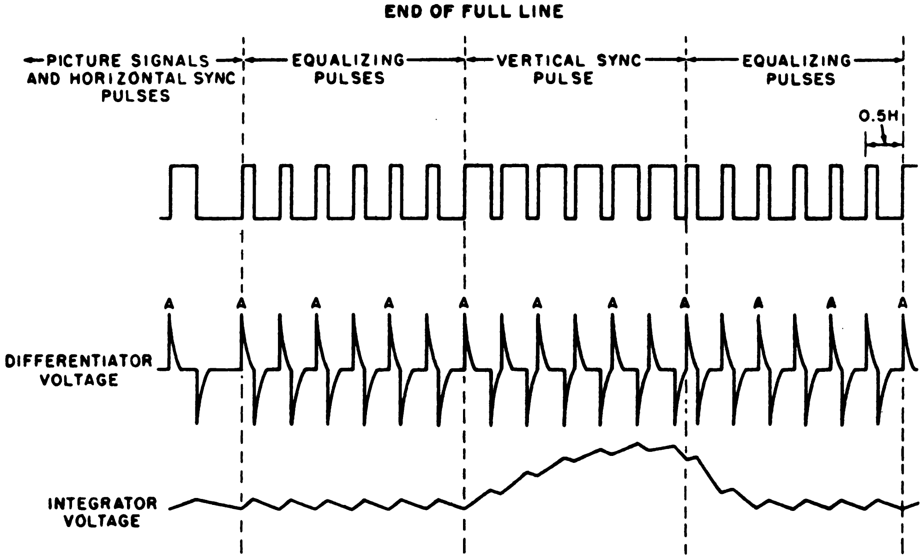

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Figure 12-16.—Form of sync pulses comprising the output integrator and differentiator voltages.

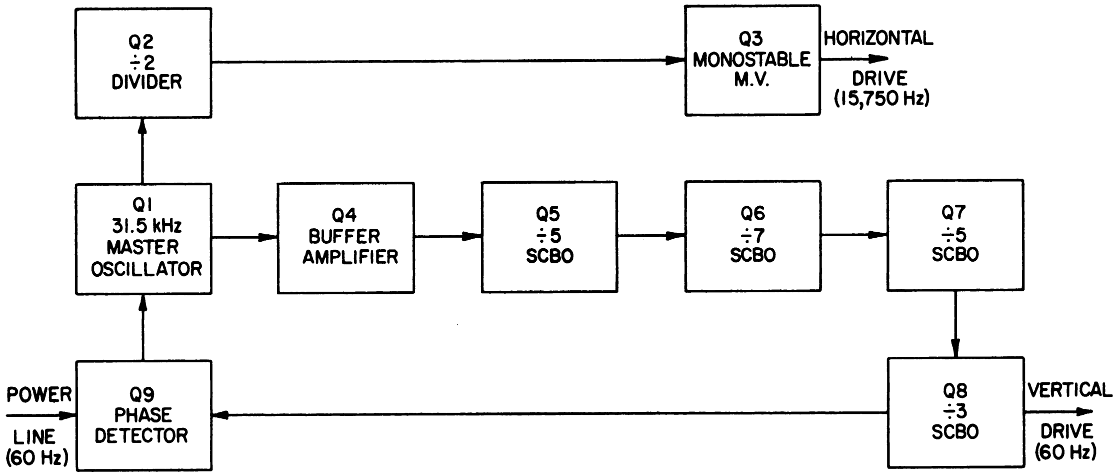

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Figure 12-17.—Sync generation using pulse counters.

horizontal and vertical sync signals are generated in a common master oscillator. Then, they are converted to signals having the required frequencies by the use of appropriate count-down circuits.

BLOCK DIAGRAM

Figure 12-17 shows the block diagram of a typical pulse-counter type of sync generator. Master oscillator Q1 generates the 31.5-kHz signal from which both the horizontal and vertical drive signals (which will later become sync signals) are derived.

The frequency and phase of the master oscillator signal are stabilized by phase detector Q9. This stage compares both the frequency and phase of the vertical drive signal with those of the 60-Hz power-line reference signal.

Frequency divider Q2 serves to halve the master oscillator frequency to 15,750 Hz. This signal is used to trigger Q3, the horizontal-drive multivibrator.

Buffer amplifier Q4 is an isolation stage used to shield the master oscillator from the loading effects of Q5, a single-cycle blocking oscillator (SCBO). Q5 is the first of four count-down circuits (Q4, Q6, Q7, and Q8) used to produce the 60-Hz vertical drive signal. Note, that Q8 has two output signals, one of which is the vertical drive signal. The other output signal is routed back to phase detector Q9 where (as stated before) its frequency and phase are compared with those of the 60-Hz power-line reference voltage. The vertical and horizontal drive signals are then routed from the sync generator to sync insertion circuits in another section of the control unit.

SYNC GENERATOR CIRCUITS

Sync generators usually consist of only a few basic circuits, with these circuits being repeated in different areas. Simplified versions of some of the more common sync generators are described in this section.

Master Oscillator

Figure 12-18 shows a simplified schematic of a 31.5-kHz master oscillator, in which Q3 is

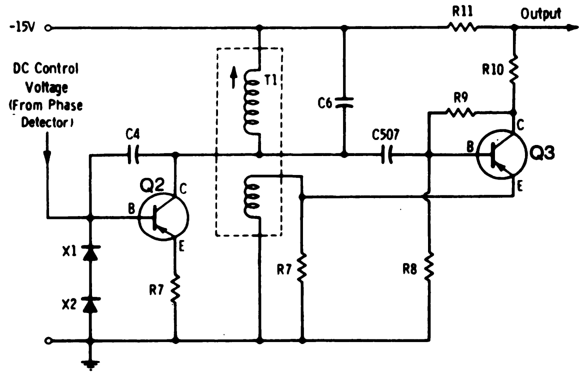

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Figure 12-18.—Master oscillator.

connected to form a modified Armstrong oscillator circuit. The frequency of this free-running master oscillator is determined by the values of C6 and T1. The inductance of T1 can be changed by adjusting the position of its movable core.

Q2 and associated circuitry comprise a reactance stage capable of changing the master oscillator frequency as a function of the dc control voltage applied to the base of Q2. The dc control voltage is the output of the phase detector previously discussed in the block diagram analysis.

In general, if the output signal of an amplifier can be made to lead or lag the input signal, that amplifier can function electrically as a variable capacitor. Refer again to figure 12-18 and imagine Q2 and associated circuitry to be a variable capacitor in series with C6. C4 and varicap diodes X1 and X2 form a capacitive voltage divider in the feedback loop of Q2. Being capacitive, the feedback loop causes the correction signal voltage to lag the signal current in the loop. The degree of lag is proportional to the amplitude of the correction signal. The apparent change in capacitance "tunes" the master oscillator to the "desired" frequency.

Phase Detector

Figure 12-19 shows a phase detector circuit such as used to provide a dc correction voltage to the reactance stage previously discussed and shown in figure 12-18. Note in figure 12-19, that a vertical drive signal is fed to the base of Q1 and a 60-Hz ac reference signal is fed to the emitter. Q1, which is normally cut off, is brought into conduction by the vertical drive signal (consisting of negative pulses). The normal phase relationship between the vertical drive and the 60-Hz reference signal is shown in figure 12-20. As long as a vertical drive pulse appears when the reference signal passes through zero, a "normal" control voltage will be produced. If, however, the normal phase relationship tends to drift, a larger or smaller correction voltage will be produced. C3 in the collector circuit (figure 12-19) acts as a filter capacitor, ensuring that a smooth dc correction voltage is applied to the reactance stage.

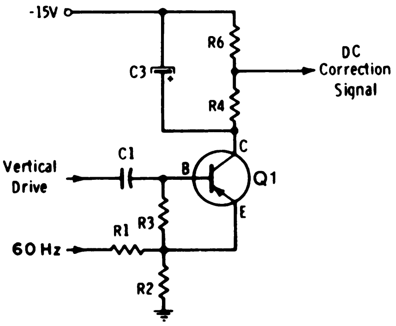

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Figure 12-19.—Phase detector.

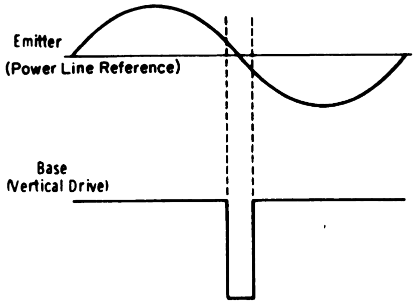

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Figure 12-20.—Phase relationships in the phase detector.

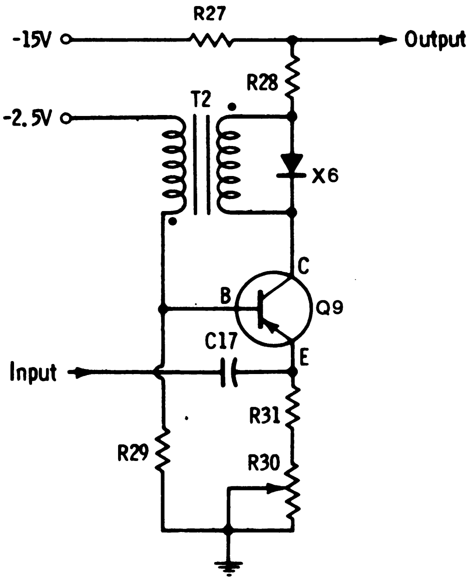

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Figure 12-21.—Blocking-oscillator frequency divider.

Frequency Divider

A single-cycle blocking oscillator (SCBO) circuit is often used as a frequency divider circuit (or count-down circuit) in sync generators. An example is shown in figure 12-21. In this circuit, Q9 is normally cut off. Input pulses from a preceding stage gradually build up a charge across C17 until a forward bias condition is achieved. As Q9 begins to conduct, a regenerative signal is coupled through T2 to the base of Q9. This regenerative signal causes Q9 to reach saturation rapidly. As soon as Q9 saturates, C17 discharges through the transistor. When C17 discharges sufficiently, Q9 abruptly stops conducting. The collapsing field around the secondary of T2 assists in driving Q9 into sharp cutoff. Diode X6 swamps T2, suppressing resonance oscillations. The values of C17, R31, and R30 have been specially chosen to allow the transistor to conduct when the appropriate number of input pulses has been applied. Figure 12-21 shows appropriate values for a 5:1 countdown.

SYNC AND BLANKING INSERTION

The earlier discussion of camera circuits revealed that the video signal is developed in the camera tube and routed through the video amplifier and peaking circuits to the control unit. After entering the control unit, the video signal is subjected to additional amplification and peaking. Video from the camera tube is referred to as "raw" video; that is, no sync nor blanking signal is included. It is therefore necessary to insert the sync and blanking signals to produce a composite video signal. Sync and blanking insertion are often performed in the control unit. Typical insertion circuits are discussed next.

Blanking Insertion

Blanking signal insertion is most often performed before sync signal insertion. Before the blanking signal can be inserted, the proper dc reference level must be established by clamping circuitry.

Clamping is needed because a coupling capacitor cannot pass dc, and it also has difficulty in passing low-frequency ac signals. Note in figure 12-22 that the RC-coupled signal assumes an

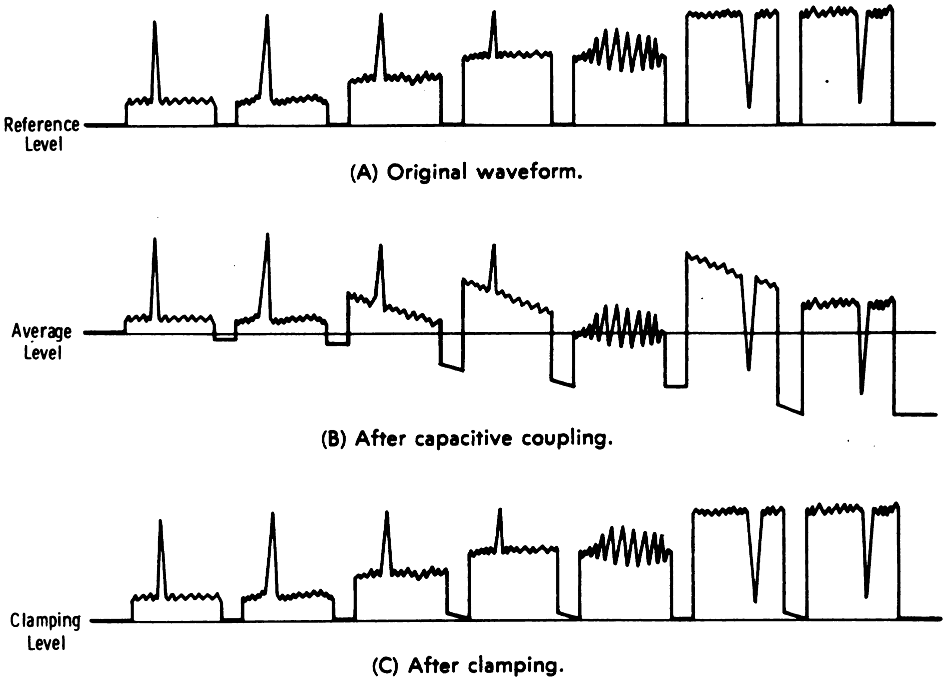

Figure 12-22.—Clamping waveforms.

average level varying about the bias voltage level of the preceding stage.

Keyed clamper circuits are used in most of the modern CCTV systems. Consequently, no clamping occurs unless a keying pulse is present. Typically, the horizontal drive signal is used as a keying pulse.

Figure 12-23 illustrates a blanking insertion circuit. In this circuit, Q8 is forward biased each time a clamping pulse (horizontal drive pulse) is applied to its base.

When Q8 conducts, the video signal is clamped at the blanking level established by R31. The clamped signal (video) is applied to the base of emitter follower Q9, amplified, and directly coupled to the base of Q10, the blanking mixer stage. Note that the level of forward bias for Q10 is determined by the potential at the emitter of Q9 which is itself controlled by adjustment of R31. The blanking signal is therefore clipped (limited) by Q10 at a level established by R31. The output of this stage is routed to a sync insertion circuit.

Sync Insertion

The sync signal is normally inserted into the composite video signal after the blanking signal has been inserted. The sync-insertion circuit used is generally a simple additive mixer similar to the sync-adding network shown in figure 12-24. In this network, sync is added (via R5 and R6) to the video signal at the video output terminals.

Isolation amplifier Q4 prevents the coupling of video to the sync input terminals. Adjustment of potentiometer R4 sets the gain of Q4, thus controlling the sync signal amplitude. Transistor Q1 is the video-output stage.

RECEIVERS

Figure 12-25 is a sectional block diagram of a TV receiver. Each of the major sections will be discussed.

TELEVISION TUNERS

Television tuners, like those of communications receivers, consist essentially of three parts: the RF amplifier, the oscillator, and the mixer. The function of the tuner, often called the front end, is to amplify the relatively weak input signal, to produce a locally generated RF signal, and to mix these two signals in such a way to produce signals at the chosen audio and video intermediate frequencies. Because of the wide band of frequencies (approximately 6 MHz) that must be passed, overcoupling and loading are employed to increase the frequency response.

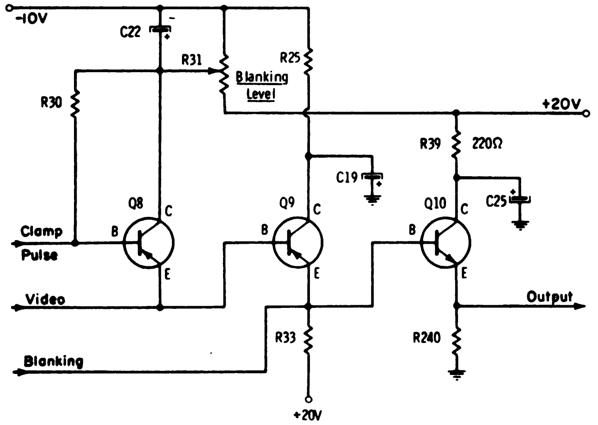

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Figure 12-23.—Blanking-insertion circuit.

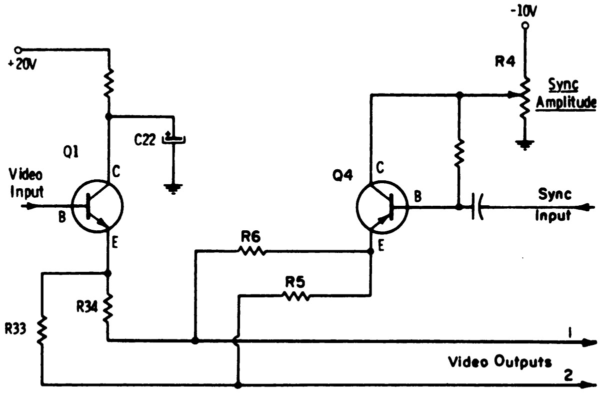

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Figure 12-24.—Sync-adding network.

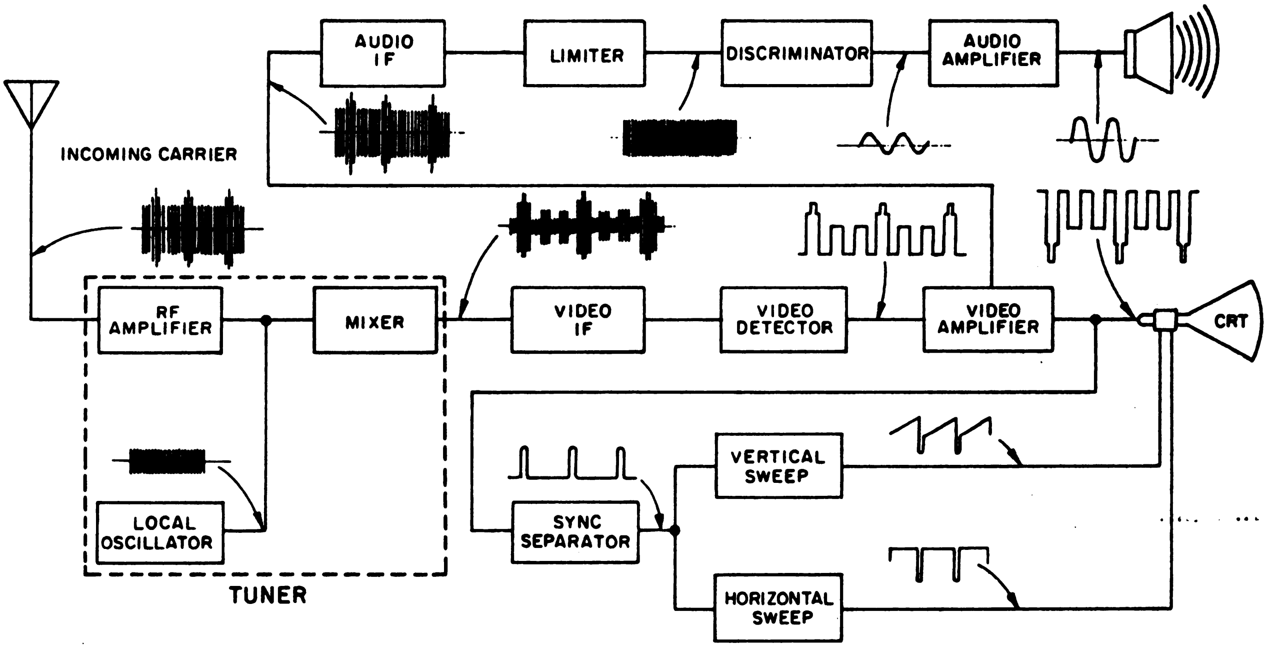

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Figure 12-25.—Sectional block diagram with waveforms.

A block diagram of a typical front end is shown in figure 12-26. A number of different methods of tuning are used. Rotary switches that connect the correct capacitors and inductors into the circuit are often employed. In some systems the "tuned line" is used, and in others, separate components are connected for each channel. Turret tuners are also widely used. In this system of tuning, elements pretuned to the desired frequency may be plugged into a clip in the turret. For compactness and precision, printed circuits are sometimes employed.

RF Amplifiers

Because the television signal available at the input of the television receiver is weak, it is desirable to amplify the signal in a stage of RF amplification before it is applied to the mixer. Various types of RF amplifiers employed in TV receivers include common emitter, pentode, and field-effect transistors (FETs), all of which are

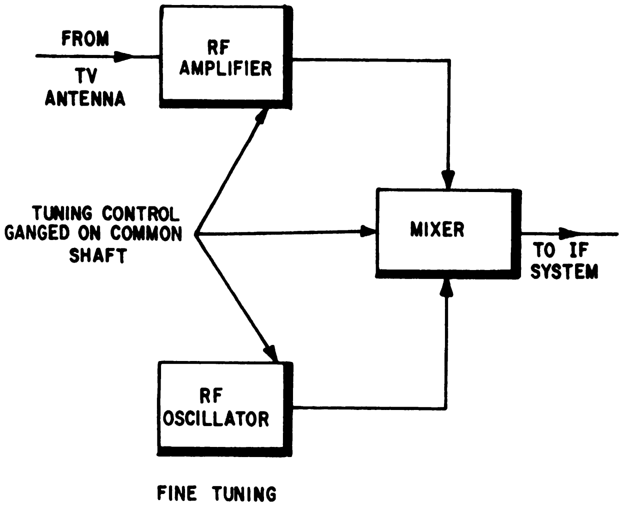

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Figure 12-26.—Block diagram of TV front end.

discussed in detail in Navy Electricity and Electronics Training Series (NEETS), Module 7. The FETs are being used extensively in television because of the advantages discussed in the following paragraphs.

ADVANTAGES OF FIELD-EFFECT TRANSISTORS (FET).—In an ordinary transistor, current flow through the device is dependent upon both the hole flow and the electron flow. Since both polarities of the charges are required for their operation, ordinary transistors are sometimes referred to as bipolar devices. In comparison, a FET is an unipolar device because the flow of current through it is either by hole flow or electron flow but not by both. Since an electron-hole combination causes noise, a unipolar device generates less noise in its operation. This is a definite advantage in RF amplifiers.

Another advantage of FET operation is its high input impedance. In this regard, it is similar in operation to the vacuum tube. Unlike transistor amplifiers which require current flow in the base circuit, and therefore require input power, a FET circuit may be designed that has virtually no current flow in the gate circuit.

The third advantage of a FET is its square law operation. Current flowing through the FET is directly proportional to the square of the voltage on the gate, which means it is a square law device rather than a linear device.

FET-RF AMPLIFIER.—Figure 12-27 shows a typical (simplified) circuit with a dual-gate FET used as an RF amplifier. An AGC voltage is developed across a voltage divider comprised of resistors R1, R2, and R3. Capacitors C1 and C2 filter the AGC voltage so that only a dc voltage is applied to the gates. The largest part of the AGC voltage is applied to gate G2.

The RF signal from the antenna is applied through C3 and developed across R3. This signal voltage appears on gate G1 . Thus, the amount of current through the FET is controlled by two voltages: the AGC voltage and the RF input voltage. The source bias is supplied by R4, and C4 is used to prevent degeneration. The output signal is taken from the secondary of transformer T1 and fed to the mixer stage.

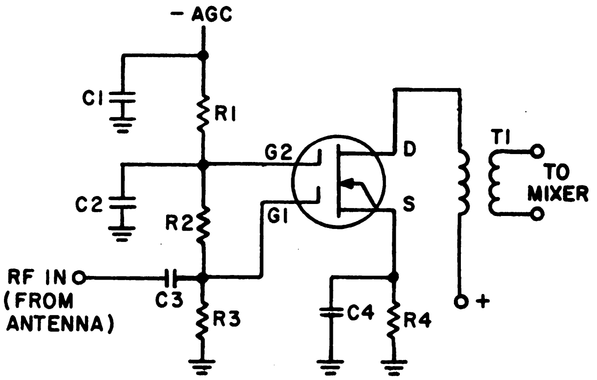

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Figure 12-27.—Dual-gate MOSFET RF amplifier.

Local Oscillators

Local oscillators provide a signal that is heterodyned in the mixer with the RF signal. As in the case of superheterodyne radio receivers, the local oscillator frequency is normally above the incoming RF frequency by a frequency that is equal to the receiver IF frequency.

The local oscillator frequency is changed whenever the channel selector is changed/tuned from station to station. The fine-tuning control varies the oscillator frequency over a narrow range. The setting of the fine-tuning control is very important if a satisfactory color picture is to be obtained.

Mixers

As shown in figure 12-26, the mixer receives a signal from both the RF amplifier and the oscillator circuits and converts these to a different frequency output, called the intermediate frequency (IF) signal. This conversion is accomplished by applying both the RF and oscillator voltages to a nonlinear amplifier. If the amplifier is nonlinear, heterodyning will take place, and the output signal will include both the sum and difference frequencies, as well as the two original frequencies. Assuming the frequency *difference* between the RF and oscillator signals is appreciable, a selective network tuned to the lower frequency component of the output will pass the desired IF only.

The dual-gate MOSFET makes an ideal mixer amplifier. This type of transistor was shown in figure 12-27. Recall it had two gates for inputs. One of the gates could be used for the RF input and the other for the oscillator input, or both inputs can be delivered to one gate, and the other used as a screen to isolate the input and output stages of the mixer.

SOLID-STATE TUNING

The solid-state tuning system is based upon the use of the "varactor" diode. This diode is also known by the name voltage-variable capacitor. The varactor is a special solid-state diode (special doping) that acts as a capacitor whose capacitance varies inversely with the amount of reverse bias applied across the diode. All varactors operate only with a reverse bias. The tuned circuits to which the varactor is connected have their resonant frequency changed merely by changing the amount of reverse bias across the varactor. The greater the reverse bias across the varactor, the less the varactor capacitance and the higher the tuned-circuit resonant frequency.

Figure 12-28 is a simplified drawing of a varactor-controlled tuning circuit. In actual practice, the switch (SW) would have positions (and respective variable resistors) for each of the VHF channels. In order for the varactor to control the frequency of the tuned circuit, it is placed across variable capacitor C2. The amount of reverse voltage on the varactor is controlled by the switch position and the setting of the variable resistors. Capacitor C1 is an isolation capacitor used to prevent dc current flow through L.

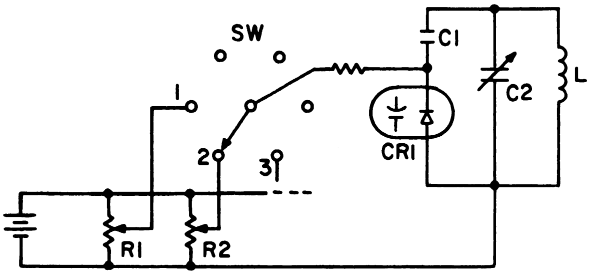

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Figure 12-28.—Varactor-controlled tuning circuit.

In actual practice, it is not possible to get a varactor diode to provide a complete capacitor range for tuning all VHF or UHF channels. Therefore, it is common practice to switch in a different inductor for the upper VHF channels.

VIDEO IF AMPLIFIERS

Video IF amplifiers perform essentially the same functions that are performed by the IF amplifiers in superheterodyne radio receivers. However, bandpass considerations, vestigial (pertaining to a remnant or remaining part) sideband transmission, the necessity for trapping unwanted sound and video beat frequencies, and other factors make the design of video IF amplifiers somewhat complex.

TRAPS

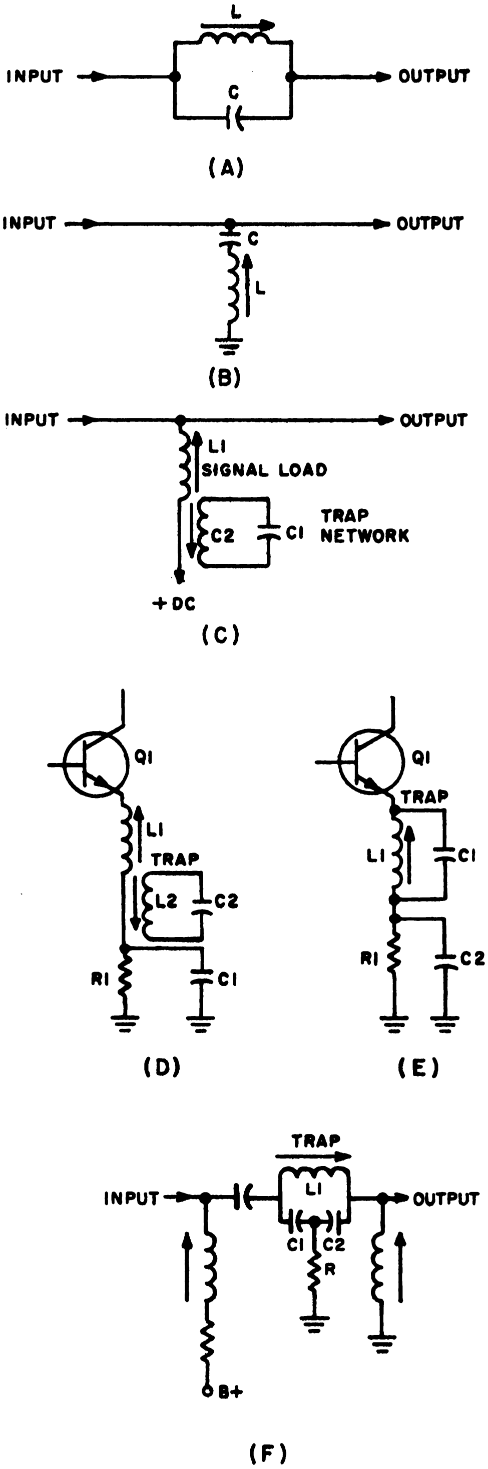
Basically, there are five types of traps used in conjunction with video IF amplifiers. These traps are known as series, parallel, absorption, degenerative, and bridged-T. For the most part, they are used in both vacuum-tube and solid-state circuits and for either monochrome- or color-TV reception. The bridged-T trap is the most widely used circuit and is indispensable in color-TV receivers.

The series trap is a parallel resonant circuit configuration (figure 12-29(A)). It is placed between two IF states and tuned to the frequency to be rejected. This type of trap circuit is a sharply tuned network designed to reject one frequency or, at most, a narrow band of frequencies. When a signal voltage at the trap frequency appears at the input of the circuit, the impedance offered by the LC network is very high and almost all of the undesired voltage is dropped across the trap. A negligible amount of the voltage appears across the input circuit of the following IF amplifier. At all other frequencies, the resonant circuit offers negligible impedance, and the desired signals pass easily.

The parallel trap is a tuned circuit which is placed across, or in shunt with, the circuit. Figure 12-29(B) shows a series-resonant circuit used in this manner. At the frequency for which it is set, the trap acts as a short circuit, bypassing the resonant frequency to ground and preventing further penetration into the circuit. At other frequencies, the trap circuit presents a relatively high impedance, permitting these signals to proceed to the following stage. It is important that the parallel trap have a very high Q so the circuit will bypass only a narrow range of frequencies.

The absorption trap, shown in figure 12-29(C), is a widely used type of rejection circuit. It consists of a coil and a fixed capacitor inductively coupled to the load inductor of an IF amplifier. When the IF amplifier receives a signal at the resonant frequency of the trap circuit, a high circulating current develops in the trap network as a result of the coupling between the trap and the load inductor. The voltage in the load coil L1 becomes quite low at the trap frequency. Consequently, very little of this interference voltage is permitted to reach the following stage. It is convenient to think of this kind of trap as being able to absorb all of the energy of the frequency to which it is tuned, and therefore no energy at that frequency is left available to pass on into the next stage.

Degenerative traps, as illustrated in figure 12-29(D) and (E), are designed to reduce the gain of an amplifier for frequencies to which the trap is tuned. These traps are used in the emitter circuit of a solid-state amplifier or in the cathode leg of a vacuum-tube circuit. In the latter application, the traps are often called "cathode traps." The two types of traps normally used to provide the



244.197

Figure 12-29.—Trap circuits.

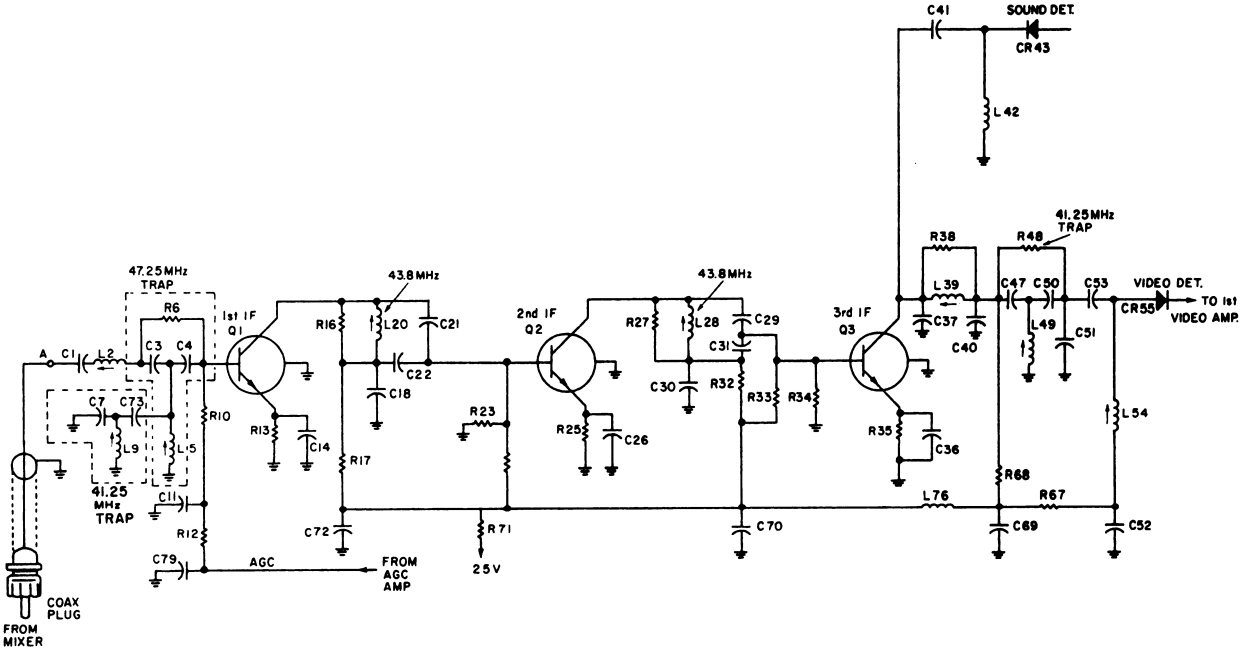
degeneration are the absorption type and the series type. Figure 12-29(D) shows an absorption type in which L1 in series with C1 forms a broadly tuned series-resonant circuit at the frequency to which the amplifier is tuned. This permits the amplifier to function normally for all signals within its frequency range. At the resonant frequency of the trap, however, a high impedance is reflected into the emitter or cathode circuit by the trap, and the gain of the stage is reduced by degeneration.

The series type of degenerative trap, illustrated in figure 12-29(E), places a parallel circuit directly into the emitter or cathode leg. At the resonant frequency of the trap, the impedance in this part of the amplifier circuit will be high, producing a large degenerative voltage and thus reducing the gain of the amplifier. At all other frequencies, the impedance of this parallel network is low. Only a small degenerative voltage appears, and therefore only a slight loss in gain occurs except at the undesired frequency.

A trap that is more complex than any of the foregoing circuits, but also more effective, is the bridged-T trap shown in figure 12-29(F). In this circuit, L1, C1, and C2 are resonated at the frequency of the signal to be rejected. Now, if the resistance of R is properly chosen, the attenuation imposed upon a signal to which L1, C1, and C2 are resonated will be great. Ratios of 50 and 60 to 1 are easily attainable using standard components. This means the strength of the desired signal at the output of the trap will be 50 to 60 times greater than the strength of the undesired signal.

CIRCUITS

While reading this section, you should refer to figure 12-30 which is a schematic diagram of a typical video IF system found in many color TV sets. This system has three NPN transistor stages that are impedance coupled and pass a band of frequencies centered at 43.8 MHz. Input to the IF system is through a plug-in link from the mixer stage in the tuner. The mixer output coil is tuned to position 42.17 MHz at the 50 percent point on the IF response curve, and the impedance of the



244.198

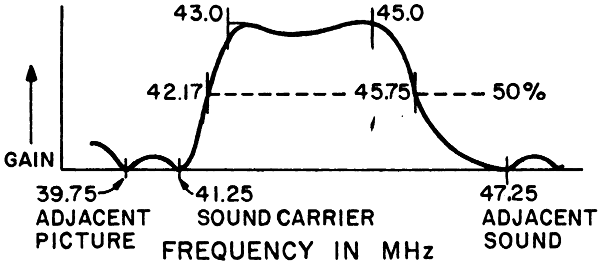
Figure 12-30.—Solid-state color IF amplifier.

coil is tapped to match the impedance of the coax link. Q1, the first IF amplifier, is coupled to the input coax link through L2 and C1. L2 is tuned to position 45.75 MHz at the 50 percent point on the opposite side of the response curve from the 42.17 MHz point. Both 50 percent points on the IF response curve are shown in figure 12-31. The mutual coupling of L2 and the mixer output coil provide a wide bandpass through the coax link.

There are two sound traps at the input to Q1—one tuned to reject the adjacent channel sound frequency at 47.25 MHz and the other tuned to suppress the 41.25 MHz associated sound carrier. The 47.25 MHz trap consists of R6, C3, C4, and L5. This trap is a bridged-T configuration and delivers, to the base of Q1, two 47.25 MHz voltages that are equal but 180 degrees out of phase. One of these voltages is developed across R6, while the other is developed across C3, C4, and L5. At the base of Q1 the voltages cancel each other, thus eliminating the adjacent channel sound carrier from the IF band. The 41.25 MHz trap is a series-resonant network consisting of C7, C73, and L9. This trap, loosely coupled to the input circuit, improves selectivity and provides better fine tuning.

In this system, AGC is applied only to the first IF amplifier stage. As the AGC voltage increases, forward bias is developed at the base of Q1. This bias increases the current flow through the transistor and, consequently, causes a greater voltage drop across R16, thus reducing the stage gain.

In the collector circuit of Q1, C21 and C22 divide the voltage developed across L20 and couple it to the base of Q2 . The junction of the two capacitors matches the impedance of the coil to the base of Q2. L20 is tuned to 43.8 MHz, which is the center of the IF system bandpass. Coupling between Q2 and Q3 is identical to that between Q1 and Q2, with L28 also tuned to 43.8 MHz. The associated sound carrier is tapped off at the collector of Q3, the third IF amplifier.



244.199

Figure 12-31.—Video IF response curve for a color set.

The output circuit of the IF system is, in effect, very similar to the input circuit. Here, L39 is tuned to position 42.17 MHz at the 50 percent point on the IF response curve, as was indicated in figure 12-31, and L54 positions 47.75 MHz at the same point but on the opposite slope. A bridged-T trap, consisting of R48, C42, C50, and L49, rejects the 41.25 MHz associated sound carrier, thus preventing it from reaching the video detector. The three sound traps in this system, two at 41.25 MHz and one at 47.25 MHz, in addition to suppressing interference, account for most of the selectivity in the IF system.

VIDEO DETECTORS

The video detector in a television receiver performs essentially the same function as the second detector in a superheterodyne amplitude-modulated radio receiver. It rectifies the signal (video and sync pulses) fed to it by the video IF system, removes the IF components, and feeds the remaining signal and sync information to the video amplifier. Various circuit arrangements, employing either diodes, electron tubes, or crystals, are used.

One type of diode detector is shown in figure 12-32. Two methods of connecting the diodes are shown. The output of CR1 has a negative picture phase, and CR2 has a positive picture phase.

In figure 12-32(A), the low amplitude positive-going picture signals correspond to the brighter portions of the picture. The higher amplitudes correspond to progressively darker portions of the picture. This corresponds to the negative picture phase.

The low amplitude negative-going picture signals of CR2 correspond to the brighter portions of the picture. The higher amplitudes correspond to progressively darker portions of the picture. This corresponds to the positive picture phase as shown in figure 12-32(B).

The following paragraph will help clarify the concept of the negative picture phase. A video

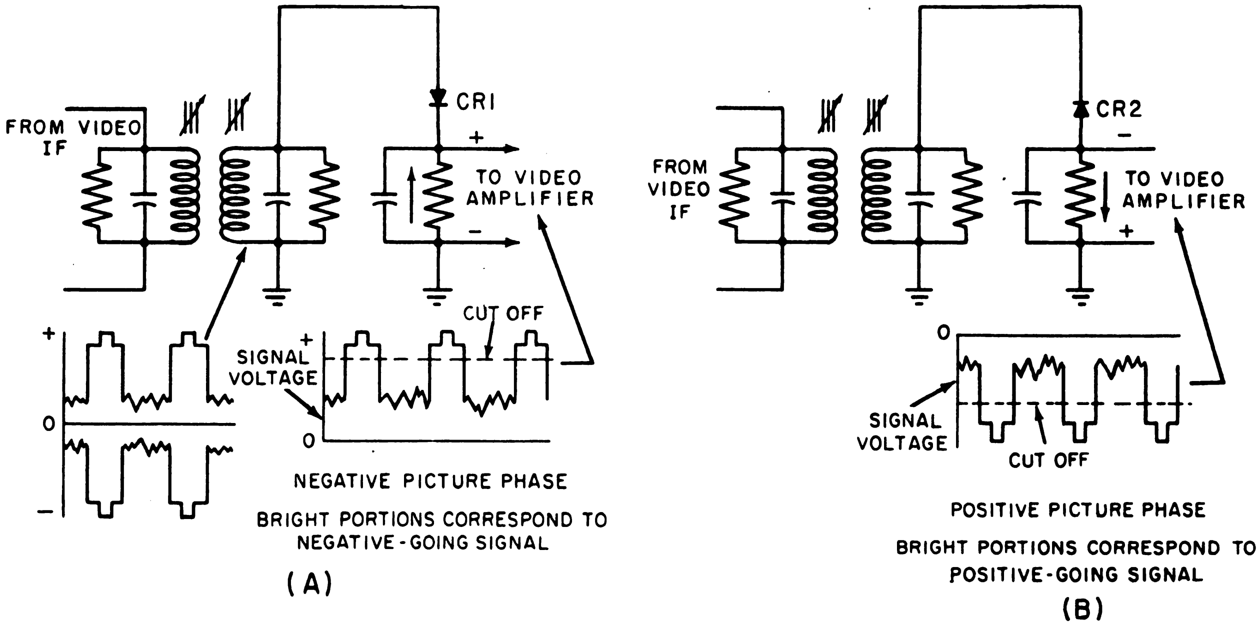


Figure 12-32.—Video diode detectors.

signal having a negative picture phase causes the cathode of the picture tube to be driven in a positive direction beyond cutoff during the blanking pulses. During the darker portions of the picture, the cathode is biased in the positive direction but not to cutoff. As a result, few electrons reach the picture tube screen, and the screen is relatively dark. During the brighter portions of the picture the cathode is driven only slightly in the positive direction, and many electrons reach the picture tube screen. Therefore, the screen is relatively bright.

The concept of the positive picture phase is presented so that it will be better understood. A video signal having a positive picture phase causes the grid of the picture tube to be driven negative below cutoff during the blanking pulses. During the darker portions of the picture, the grid is driven considerably negative but not to cutoff. Consequently, fewer electrons reach the picture tube screen, and the screen is relatively dark. During the brighter portions of the picture, the grid is driven only slightly negative, and many electrons reach the picture tube screen. Therefore, the screen is relatively bright.

The output of the detector in the receiver may have a positive or a negative picture phase as indicated in figure 12-32, irrespective of the type of transmission used. In either case, the video amplifiers must supply a signal having a positive picture phase to the grid of the picture tube. If the signal is applied to the cathode of the picture tube, it must have a negative phase.

Look at figure 12-25 for a review of signal processing. Up to this point, you have seen that the television signal has been received and amplified by an RF stage, converted to another frequency (IF) by means of a mixer, further amplified by the IF stages, and rectified by the diode detector. The strength of the signal at the output of the detector is not sufficient to drive the picture tube; therefore, one or more stages of video amplification are necessary.

VIDEO AMPLIFIERS

After the video signal (containing the video information and the blanking and sync pulses) has been rectified in the second detector, it must be amplified in one or more video amplifiers before it is applied to the picture tube. Because a wide band of frequencies must be passed without discrimination by the video amplifiers, they must be carefully designed. Special high- and low-frequency compensating circuits must be used to extend the approximate range of frequencies passed from 30 hertz to 4 MHz. In other words, frequency distortion must be eliminated as much as possible.

The low frequency video components include the low frequency ac variations (represented on the picture screen as portions of the image that does not contain fine detail), the blanking pulses, and the sync pulses (vertical and horizontal). The high frequency video components are the high frequency ac variations that produce the fine detail on the picture screen. In addition to the low frequency and the high frequency components in the transmitted signal, there is a zero frequency, or dc component present.

If all of the frequency components are not properly amplified in the video amplifier section, a distorted image is produced. The distortion may appear as a lack of fine detail, a lack of image sharpness in the larger objects, or a lack of contrast.

In addition to frequency distortion, phase distortion must also be eliminated as much as possible. Phase distortion means that certain components (frequencies) that make up complex waveforms are not passed by the amplifier in the same length of time that other frequencies are passed. For example, in resistance-coupled amplifiers, the coupling capacitor and the grid resistor, acting together, cause a phase shift that varies with the frequency. Phase distortion may alter the background of the picture shown on the television screen; portions that should be white may be gray or even black. At the lower frequencies, excessive phase shift may cause larger objects to be blurred on the screen. At the higher frequencies, excessive phase shift causes the fine detail to be blurred.

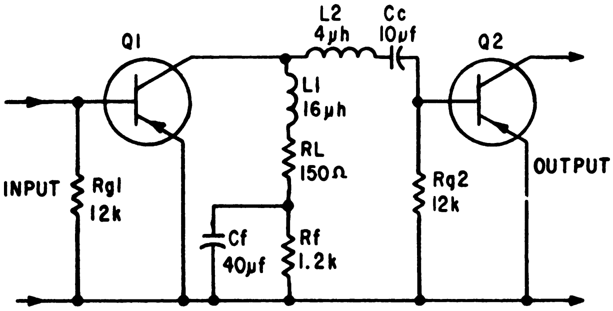
The average resistance-coupled amplifier has a flat response of only a few thousand hertz; therefore, it is not suitable for amplifying video frequencies. In order to amplify the higher frequencies as much as the middle range of frequencies, it is necessary to use some form of high frequency compensation. This type of compensation commonly takes the form of shunt compensation, series compensation, or a combination of both. An example of the combination type of compensation is shown in figure 12-33.

In a resistance-coupled amplifier, the output capacitance of the first amplifier stage, the distributed capacitance of the wiring, and the input capacitance of the second amplifier stage tend to shunt the high frequencies of the first stage to ground. Therefore, there is less output voltage at these frequencies available to the second stage. The high frequencies are, therefore, not amplified as much as the middle range of frequencies.

The shunting effect is compensated for (or the frequency range extended) by the use of a small inductor (shown as L1 in figure 12-33) inserted in series with the load. The value of this inductor is chosen so that it will neutralize the distributed (output and input) capacitance of the circuit. That is, this inductor together with the distributed capacitance, forms a parallel-resonant circuit that is resonant at a frequency where the response curve begins to fall appreciably. The frequency range is thereby extended. This type of compensation is called shunt compensation, and the coils are called peaking coils.

Series compensation is also used. In this case, a small inductor (shown as L2 in figure 12-33) is added in series with the coupling capacitor and forms a series-resonant circuit (resonant at a frequency where the response curve begins to drop) with the distributed capacitances. At resonance, increased current flows through these capacitors, and larger voltages are available at the input of Q2. To prevent a sharp peak in the response curve, a resistor is shunted across the series inductor.

In order to amplify the lower frequencies as much as the middle or high range of frequencies, it is necessary to use some form of low frequency compensation. At low frequencies, the reactance



20.435

Figure 12-33.—Transistor video amplifier.

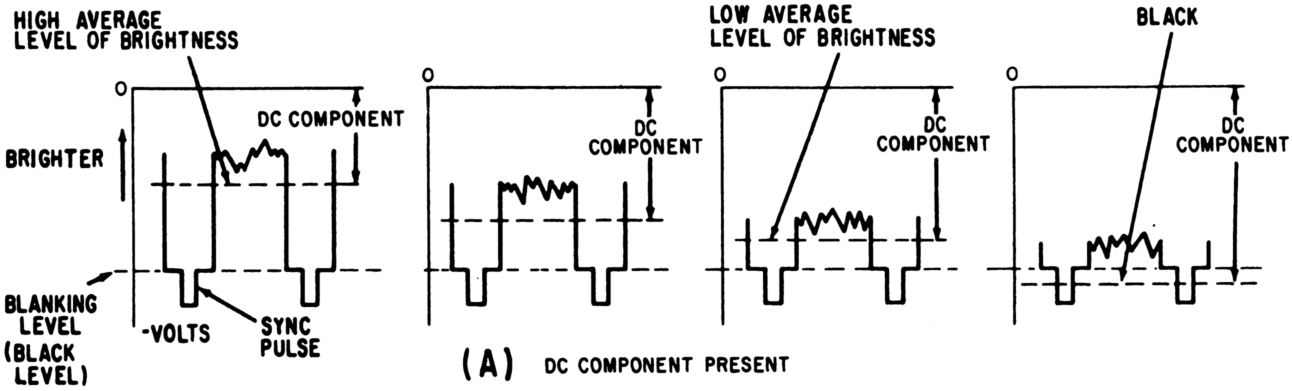
of the coupling capacitor is large, and much of the signal voltage is dropped there and not available at the base input. If a large coupling capacitor could be used, the stray capacitance and leakage current would be increased. Of course, a coupling capacitor introduces some phase shift at low frequencies.

It is possible to compensate for the loss in gain and the increase in phase shift at the lower frequencies by dividing the load resistor into two parts and bypassing one part with a capacitor. Look at figure 12-33. The load resistance is divided into two parts by using RL and Rf. One part is bypassed by using Cf. At the lower frequencies, the load includes both resistors; therefore, the output voltage is higher. At the higher frequencies, a portion of the load is effectively bypassed by the capacitor, and the output is proportionately lower.

DC RESTORERS

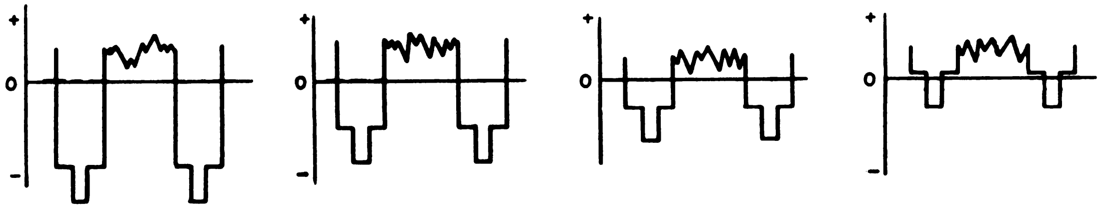
The dc restorer (or clamper) restores the dc component of a pulse waveform after this component has been removed by the passage of the waveform through the coupling capacitor in the video amplifier stage. It is necessary to reinsert the correct dc component at the input of the television picture tube if the correct level of background illumination is to be maintained. Also, if the correct dc component is not reinserted, the blanking level will vary (instead of remaining constant as it should), and retrace lines will appear on the screen during the time the blanking voltage is insufficient to cut off the picture tube during retrace.

The average brightness of one scanned line may differ widely from the average brightness of another scanned line, as shown in figure 12-34(A).


HIGH AVERAGE LEVEL OF BRIGHTNESS
0
DC COMPONENT
BRIGHTER
BLANKING LEVEL (BLACK LEVEL)
-VOLTS
SYNC PULSE
0
DC COMPONENT
LOW AVERAGE LEVEL OF BRIGHTNESS
0
DC COMPONENT
BLACK
0
DC COMPONENT

(A) DC COMPONENT PRESENT

WHEN THE VIDEO SIGNAL PASSES THROUGH A COUPLING CAPCITOR, THE DC COMPONENT IS REMOVED, LEAVING AN AC SIGNAL THAT VARIES ABOUT THE ZERO LINE AS SHOWN BELOW.



(B) DC COMPONENT REMOVED

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Figure 12-34.—Function of the dc component in the video signal.

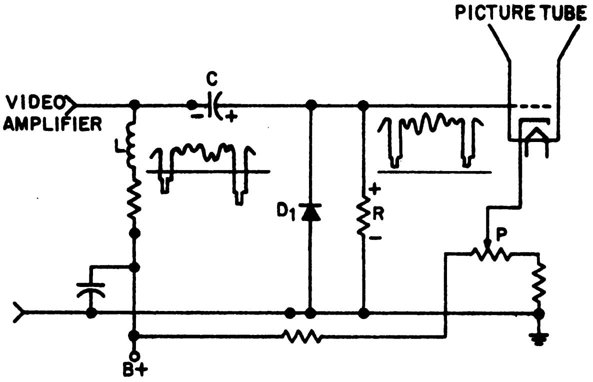

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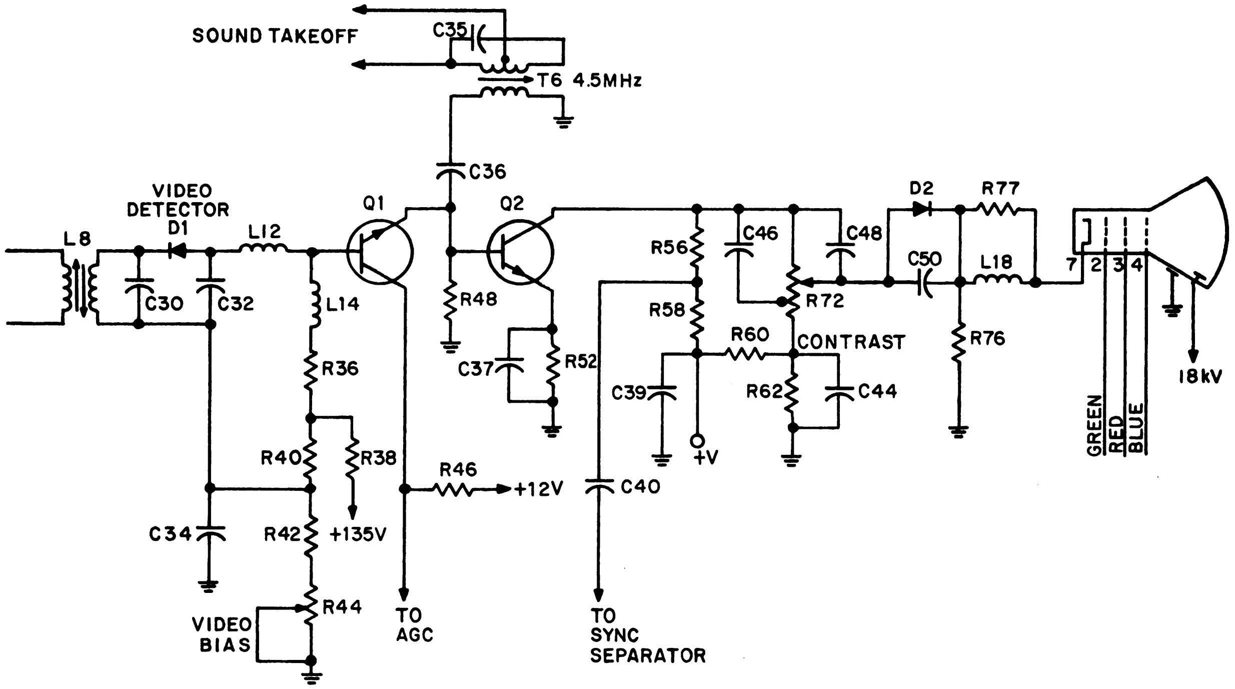
Figure 12-35.—Diode dc restorer.

The average dc component depends on the average brightness of a scanned line. A low dc component in the negative direction means a high level of brightness exists during that line. A high dc component in the negative direction means a low level of brightness exists during that line. The average dc component therefore establishes the blanking level.

Figure 12-34(B) illustrates what happens when the dc component is removed by the passage of the video signal through a coupling capacitor. Although the picture tube may be biased so that it is not driven in a positive direction beyond a certain value, nevertheless the blanking level varies and the retrace is often visible. The background brightness level also differs from that at the transmitter.

A simplified dc restorer circuit is shown in figure 12-35. The function of the circuit is to restore the dc component that was lost when the video signal passed through the coupling capacitor of the video amplifier. Dc restoration is accomplished by adding enough dc voltage to the instantaneous ac signal to bring the blanking voltage to the cutoff point.

The dc diode restorer acts in the following manner. Without the diode, the input signal voltage appears as shown in figure 12-34(B).



244.201

Figure 12-36.—Direct-coupled video amplifier stages.

During the negative portion of the cycle (when the blanking and synchronizing pulses are active), the diode (figure 12-35) conducts because its cathode is negative and its plate is positive. Capacitor C charges rapidly through the diode and has the polarity indicated. The amount of the charge (voltage across C) depends on the strength of the input signal.

During the positive portion of the signal, shown above the 0 line in figure 12-34(B), the diode cannot conduct, and C (as shown in figure 12-35) discharges slowly through R. A positive potential, which reduces the bias on the picture tube, is applied between grid and cathode during the scan interval between the blanking pulses. During this interval, the diode is effectively an open circuit, and the video signal appears across R in series with the dc voltage supplied by C. The greater the input voltage, the less the net bias remaining on the grid of the picture tube and the higher the average brightness. Thus, the condition existing in figure 12-34(A) is reestablished.

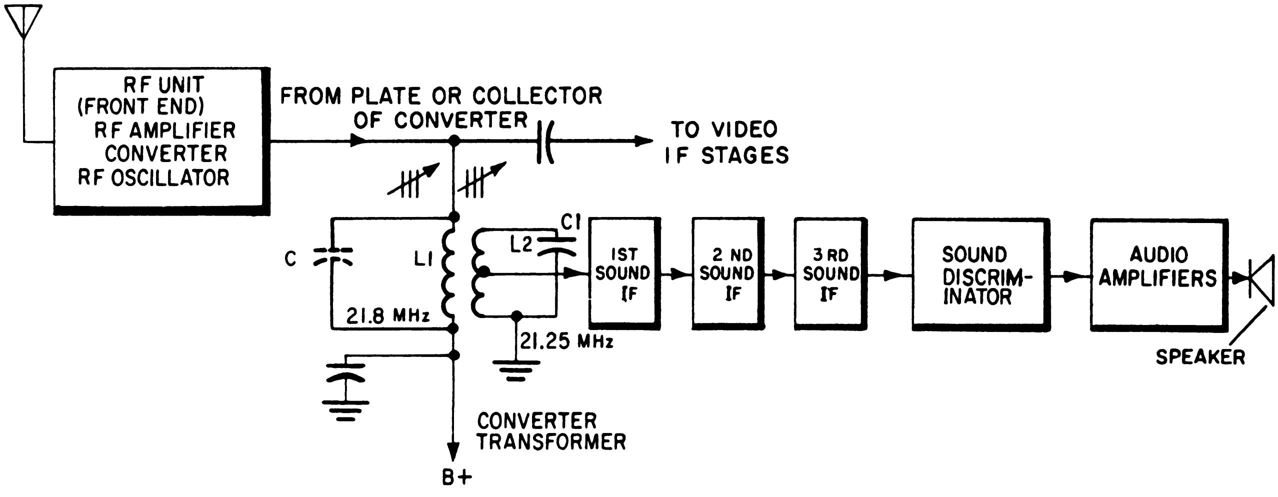
When direct coupling is employed between all stages in the video amplifier section, including the coupling stage between the video detector and the first video amplifier and picture tube, dc restoration is not required. An example of this direct coupling is shown in figure 12-36. Detector D1 is direct coupled to first video amplifier Q1 through peaking coil L12. This is an emitter-follower stage which develops a signal across R48. The base of second video amplifier Q2 receives its signal directly from the emitter of Q1. The second amplifier is a conventional (common emitter) amplifier stage direct coupled to the picture tube through the contrast control, diode D2, and peaking coil L18. Diode D2 is used to compensate for nonlinearity in transistor amplifier Q2 on high-amplitude signals.

TELEVISION SOUND SYSTEMS

The sound system of a television receiver is essentially the same as that of an FM receiver. An important difference, however, is the system used for IF amplification. There are two systems in use—the split-sound system and the intercarrier-sound system.

SPLIT-CARRIER SOUND SYSTEM

A block diagram of a split-carrier sound system is shown in figure 12-37. Although a large number of the newer television receivers use intercarrier sound, some sets still employ the split-sound system. In the split-sound system, the sound IF is removed at the output of the converter



40.222

Figure 12-37.—Split-carrier sound system.

(or from the first video IF) and amplified in a series of sound IF amplifiers.

INTERCARRIER-SOUND SYSTEM

A block diagram of an intercarrier-sound system is shown in figure 12-38. Its obvious advantage is that the sound is amplified along with the video, which means fewer audio stages are necessary.

The carrier IF in the output of the RF unit is the same as those in the output of the RF unit in the split-sound system. Because the IF stages in the intercarrier system must pass both the picture and the sound IF carrier, the bandpass must be wide enough to pass both of these frequencies.

INTEGRATED-CIRCUIT (IC) SOUND SYSTEM

An ideal IC for a TV sound section would have five terminals: one for ground, one for power, a 4.5 MHz input, a lead for the volume control, and a connection which goes directly to the speaker. Figure 12-39 shows a TV FM sound circuit which contains an IC and 13 other components. The two coils are single-slug tuned and simple to align.

The power transistor and output transformer are required because ICs are usually small devices with low-power dissipation. Some additional gain is therefore required to change to the power and impedance requirements of a 4-ohm, 2-watt speaker.

The two IF amplifiers are not transformer or resonant-circuit coupled. Instead, adequate selectivity is obtained with just the resonance of L1 and C2. A gain of 2,000 at 4.5 MHz is typical. This large gain saturates the last IF amplifier and produces the square-wave signal required for the quadrature detector.

The quadrature detector is an FM detector circuit that acts as both a discriminator and a limiter in one stage. This type of FM detector is easily produced as part of an integrated circuit. Tuning merely requires making L2 and C2 resonant at 4.5 MHz.

The audio-voltage amplifier is a three-stage, four-transistor, dc-coupled amplifier. Direct coupling allows a good bass response and also avoids the use of capacitors. Note that, except for the speaker transformer and the two capacitors associated with the volume control, this system would have a bass response down to dc.

PICTURE TUBES

A monochrome picture tube is a specialized form of the cathode-ray tube. An electron gun in the tube directs a beam of electrons toward a fluorescent material on the screen, which glows when struck by the electrons. Between the gun and

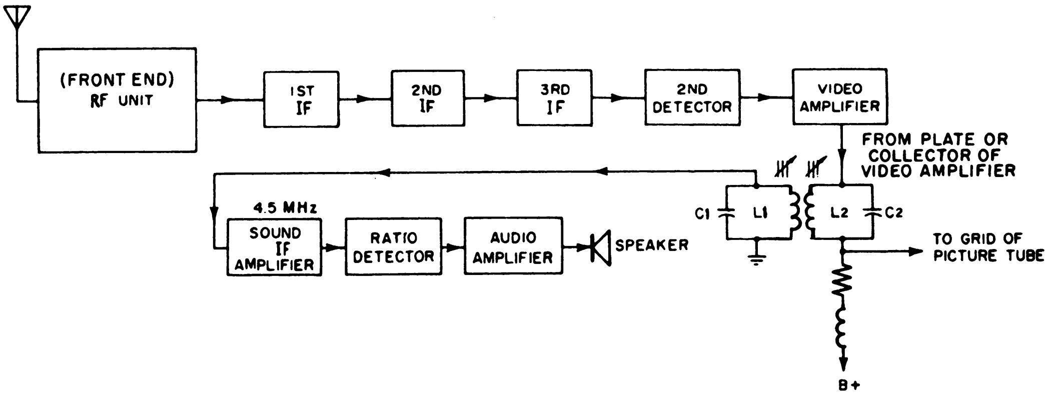


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Figure 12-38.—Intercarrier sound system.

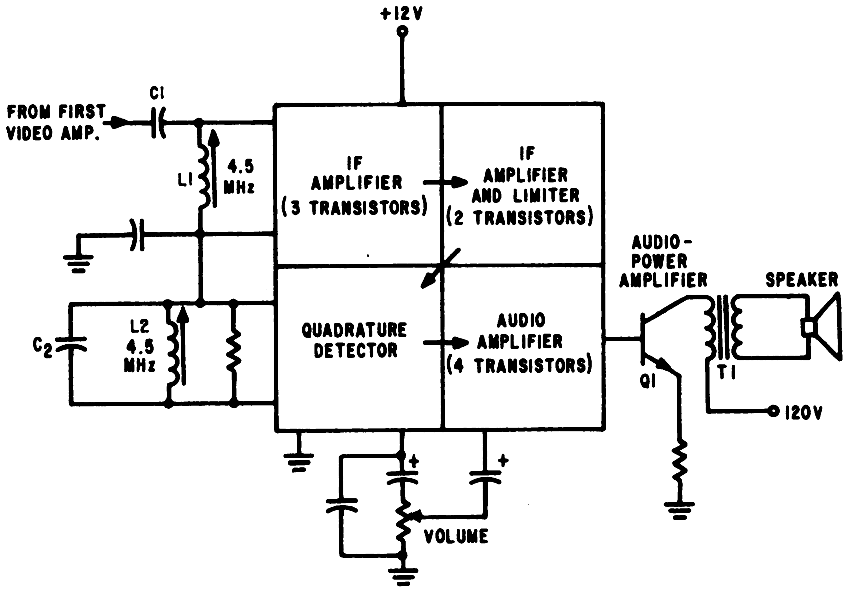

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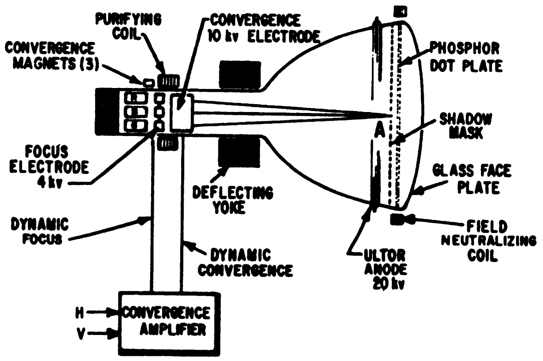
Figure 12-39.—IC sound system.

the screen are deflection coils which deflect the beam horizontally and vertically to form a raster. The brightness of the screen at any point depends upon the number and velocity of electrons striking that point. The brightness of the picture is controlled by varying the grid-bias voltage with respect to the cathode voltage. This bias can be changed by varying either the cathode voltage or the grid voltage.

Color picture tubes operate on the same basic principle as monochrome picture tubes. The difference between the two systems is the types of phosphors which coat the screen. The different types of phosphors produce colors when struck by electron beams. Three basic or primary colors are used in combination to produce all the other desired colors. These primary colors are red, green, and blue. In a three-gun color picture tube (figure 12-40), there is a separate gun for each of the color phosphors. The tube's screen consists of small, closely spaced phosphor dots of red, green, and blue. The dots are arranged so a red, green, and blue dot form a small triangle. The shadow mask provides a centering hole in the middle of the triangle of dots. The convergence electrode causes the three separate electron beams to meet and cross at the hole in the shadow mask.

Each electron gun is electrostatically focused by a common grid voltage. In other words, each gun has its own electrode, but all three are connected together requiring only one grid voltage. The three electron beams scan the screen as controlled by the deflection yoke which is



244.42

Figure 12-40.—Color picture tube.

mounted externally around the neck of the tube. As the three beams scan the phosphor screen horizontally and vertically in the standard scanning pattern, the dot triads will light according to the video input signals (figure 12-41).

The purifying coil produces a magnetic field within the tube which aligns the electron beams parallel to the neck of the tube. Rotating the purifying coil adjusts the electron beams so they strike their respective color dots without striking neighboring dots. When this adjustment is made for the red dots, the other two electron beams are aligned as well.

The high voltage anode is a metallic ring around the tube. The field neutralizing coil aids color purity at the outer edges of the picture tube. A metal shield, called a mu-metal shield, is placed around the bell of the tube to prevent stray magnetic fields from affecting the electron beams.

COLOR CIRCUITS

A color television receiver, as shown in figure 12-42, contains many circuits which are markedly different from the circuits used in monochrome receivers. The differences are outlined in the following paragraphs.

The tuner and amplifier stages in color receivers are designed to pass a wider band of frequencies than do conventional monochrome receivers. Wideband characteristics in these stages are necessary to assure uniform amplification of the high-frequency color subcarrier sidebands that carry the chrominance (color) information.

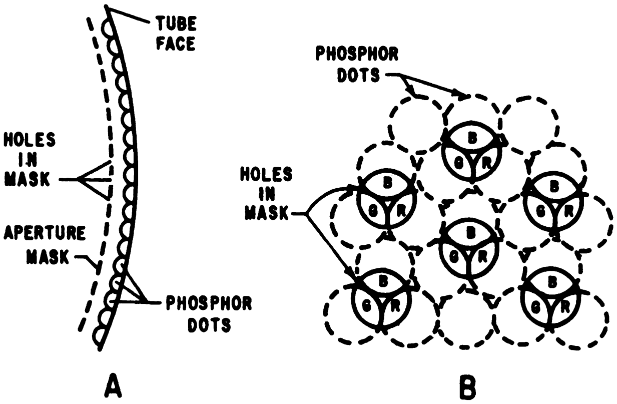


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Figure 12-41.—Color picture tube. (A) Side view, (B) front view.

Usually, the video amplifier stage in monochrome receivers consists of only one stage of amplification, while color receivers usually contain three stages of amplification. Additional stages of amplification are made necessary because the luminance signal in color receivers is used to drive the cathodes of all three electron guns in the CRT, as compared to the single-gun monochrome CRT.

A video delay line, usually located between the video output stage and the CRT, is used to delay the luminance signal for a fixed period of time so the luminance and chrominance information arrive at the CRT simultaneously. As shown in the block diagram (figure 12-42), this fixed delay is necessary because the chrominance signals pass through additional stages before being applied to the control grids of the CRT. Were it not for the delay of luminance information, the two signals would not arrive in coincidence, and a distorted video presentation would result.

Due to the use of an aperture mask type of picture tube, the brightness of a color receiver is characteristically low. This means that higher voltage is necessary to maintain adequate brightness. The output voltage of the high voltage supply is nominally 20-25 kV as compared with 15-18 kV for monochrome receivers. All three electron guns must be sharply focused onto the screen to obtain good monochrome and color reproduction. The focus rectifier in color receivers provides a variable focus voltage (4 to 5 kV) that is applied to the electrostatic focus elements of the CRT. The load of the high-voltage rectifier must be held fairly constant in color receivers. Otherwise, severe blooming or shrinking of picture size will occur during reception of signals having a varying brightness level. The voltage regulator circuit provides a fairly constant anode voltage regardless of the brightness level of incoming signals.

The color demodulator section is the "heart" of the color television receiver. In this section, the 3.58 MHz subcarrier sidebands are demodulated to produce color information signals. The color information signals are then applied to a matrix where color difference signals are produced by

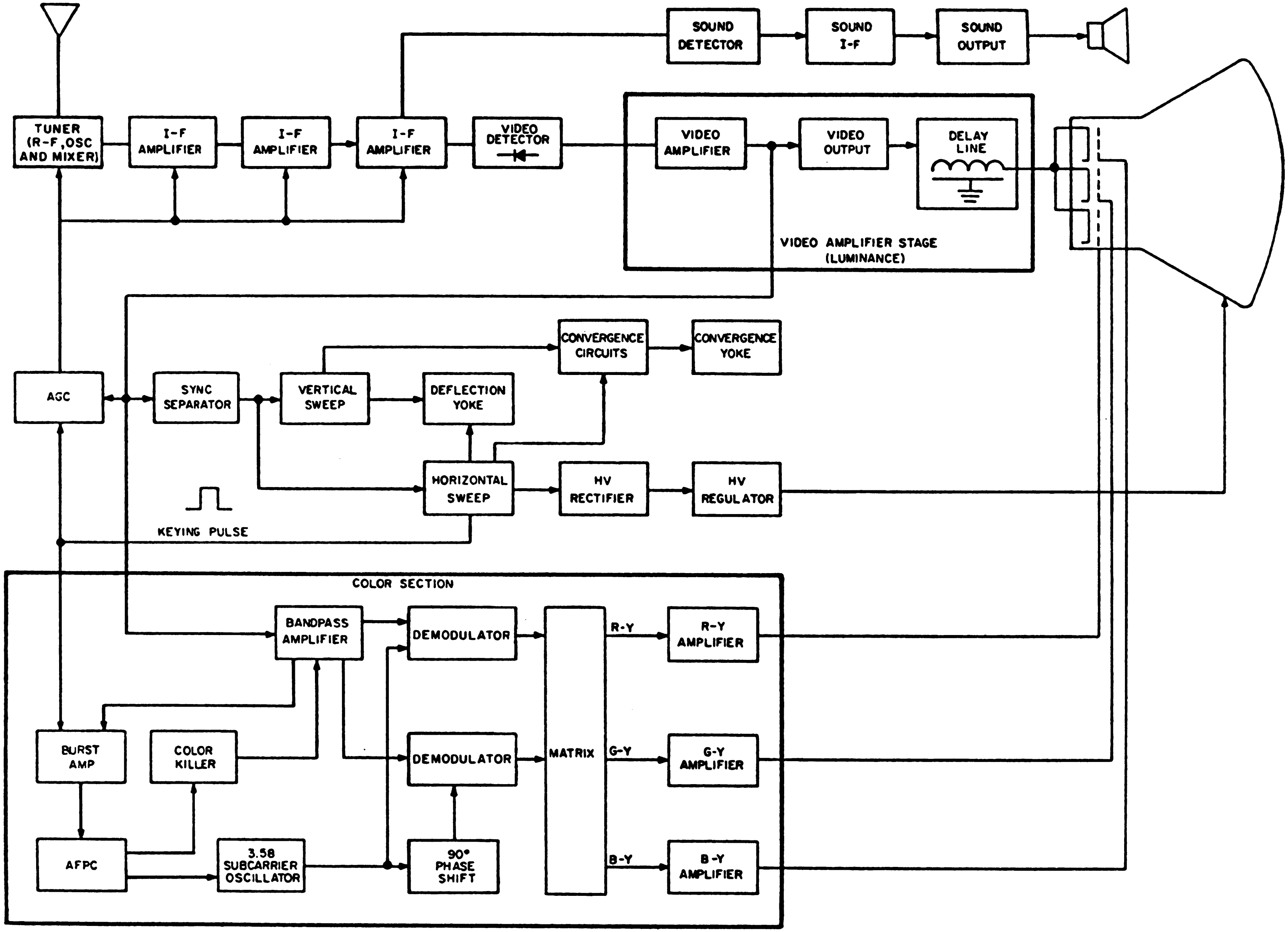

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Figure 12-42.—Color television receiver, block diagram.

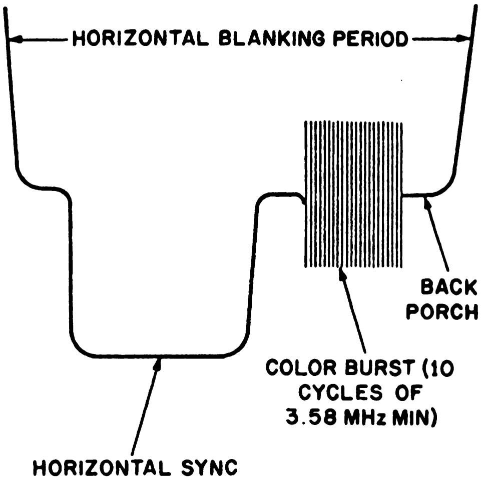
matrixing proportionate amounts of the demodulated signals. The color difference signals are in turn amplified and applied to the control grids of the CRT in the proper proportions to reproduce the televised scene.

The color convergence circuits provide a secondary control over the electron beam of each gun. Convergence of the three electron beams to exact locations on the face of the CRT is necessary to produce good monochrome and color images on the three-gun CRT.

Other differences in color receiver circuits, such as automatic color control, tuning indicators, and color reception indicators, serve to simplify the operation of front-panel controls.

BANDPASS AMPLIFIER

The chrominance 3.58 MHz subcarrier signal and the color-synchronizing burst signal are coupled from the first video amplifier to a bandpass amplifier (figure 12-42). The bandpass amplifier is tuned to amplify the subcarrier frequency and reject the lower-frequency video signals. The 3.58 MHz subcarrier sideband signal must now be demodulated to recover the color information. Consequently, a locally generated 3.58 MHz oscillator signal must be mixed with the subcarrier sideband to produce the chrominance signals. The frequency and phase of the locally generated signal is critical. It must be nearly identical to that of the station transmitter in order to recover exact color information. Therefore, the local oscillator is constantly synchronized by the burst reference signal. At the output of the bandpass amplifier, the burst signal, which is composed of approximately 10 cycles of the 3.58 MHz signal generated by the transmitting station's oscillator (figure 12-43), is selected by a burst separator. The burst separator in this instance is a time-gated amplifier that is gated, or "keyed" on, by a horizontal pulse from the flyback transformer during the horizontal retrace time. The burst signal is then applied to the automatic frequency and phase control (AFPC) circuits which control the 3.58 MHz local oscillator.

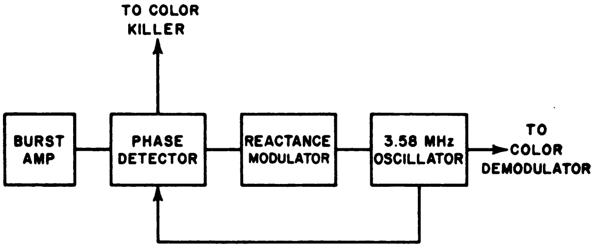

HORIZONTAL BLANKING PERIOD
BACK PORCH
COLOR BURST (10 CYCLES OF 3.58 MHz MIN)
HORIZONTAL SYNC

40.244

Figure 12-43.—Location of color bust on horizontal sync pulse.

AUTOMATIC FREQUENCY AND PHASE CONTROL (AFPC) CIRCUIT

The burst signal is coupled to the AFPC circuit, as shown in figure 12-42. The reference circuit is usually one of two types: the stable oscillator-phase detection type or the frequency-phase detection supplemented type. Only the former will be discussed. The stable oscillator-phase detection type of AFPC, shown in figure 12-44, accepts the keyed signal from the burst gate and applies it to a phase detector. In the phase detector, the locally generated oscillator signal is compared with the incoming burst signal and an error or corrective voltage is developed. The error



40.245

Figure 12-44.—AFPC circuit.

voltage is applied to a reactance modulator which is connected in parallel across the 3.58 MHz oscillator tank. The reactance modulator acts as a variable capacitor, with its capacitance either increasing or decreasing, depending upon the polarity of the voltage applied. Thus, when the phase of the local oscillator changes appreciably, the voltage developed by the phase detector changes the capacitance of the reactance modulator, and the oscillator output signal shifts in phase in order to correspond to the burst signal.

The frequency of the local oscillator is primarily controlled by an input crystal tank circuit. However, when the local oscillator does drift off frequency, the phase detector error or correction voltage causes the oscillator to swing through its frequency range until the phase and frequency error voltages equal zero, and the oscillator locks in.

COLOR-KILLER CIRCUIT

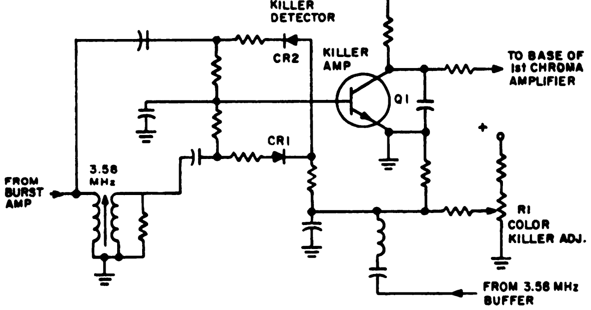
The purpose of the color-killer circuit is to disable the color circuits when a monochrome signal is being received. Usually this is accomplished by biasing the bandpass amplifier below cutoff. No signal passes until the burst is applied to the color-killer circuit. In order to demonstrate the effectiveness of a color-killer circuit, assume that a signal of high noise characteristics is present at the input of the bandpass amplifier. The transistor goes into conduction, which enables the color circuits and results in a colored noise presentation on the CRT. The color-killer circuit prevents this noise presentation on the CRT by sensing the absence of the color burst signal. If the burst is absent, the color-killer circuit conducts and applies bias to the bandpass amplifier, thereby cutting off the color circuits. When the color-killer circuit senses the presence of the burst signal, such as by sensing a negative voltage at the output of the phase detector shown in figure 12-44, the color-killer circuit ceases to conduct, and thereby permits the bandpass amplifier to admit the chrominance information.

In later model receivers, various circuits have been devised to eliminate this undesirable "color" during monochrome transmission. One simple method involves merely biasing off the bandpass amplifier by adjusting the familiar "color control" on the front of the receiver. However, a second and more sophisticated method of color-killer circuit operation is the circuit shown in figure 12-45. This diode phase detector circuit uses the 3.58 MHz burst signal and the 3.58 MHz signal from the crystal oscillator as inputs. It compares the phase of these two signals and generates a dc output proportional to their phase difference.

Note the location of the color-killer potentiometer (R1). It is adjusted so the Q1 is biased up to a point just slightly below cutoff. If the bursts are not present in the video signal, then a large phase error is detected. This causes a positive bias to add to the bias mentioned above and Q1 turns on. This sends a negative bias to the chroma amplifiers, turning them completely off. If color bursts are present, the color-killer detector does not turn Q1 on, thereby allowing the chroma amplifiers to operate normally.

CHROMA DETECTORS

The purpose of the chroma detector circuit is to recover the chrominance components from the 3.58 MHz subcarrier sideband. These are transmitted by the station transmitter. The chrominance components are then used by the receiver circuits to reproduce a replica of the televised scene of the face of the CRT.



244.204

Figure 12-45.—Color-killer circuit.

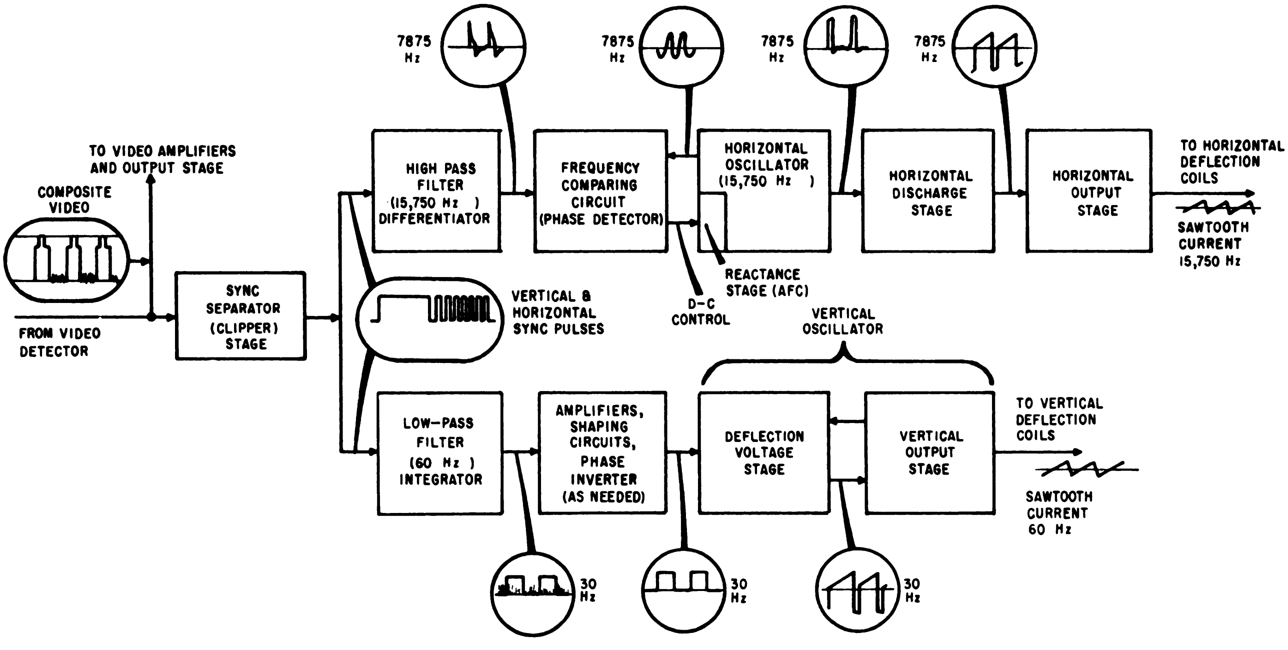
MATRIX AND COLOR DIFFERENCE AMPLIFIER CIRCUITS

Matrix circuits are designed to reassemble the chrominance signals to form the original camera output signals. The signals corresponding to the camera video signals are combined with the luminance signal to produce a replica of the televised scene on the face of the CRT. Matrix circuits take on many forms, and the particular circuit used in any one individual receiver depends upon the receiver design. At the transmitter, the luminance signal (E_Y) and chrominance signals (E_I and E_Q) were formed by combining proportionate parts of the red, green, and blue camera tube outputs. It would seem, then, that to reverse the process a similar matrix should be used at the receiver. At the receiver, however, the chrominance signals are demodulated to form color difference signals of R-Y and B-Y, rather than the transmitted chrominance signals of E_I and E_Q. (The reason is based on the economic advantages of using equiband circuits.) As a general rule, the luminance (E_Y) signal is combined with the color difference signals in the color CRT; however, this again is determined by receiver design.

SYNCHRONIZING CIRCUITS

The previous discussion on TV was focused primarily on delivering the video signal to the picture tube. Equally important, from the point of view of overall receiver operation, is the system by which the various circuits are synchronized with those at the transmitter and made to function together to produce the desired picture. Refer to figure 12-42 for an overview of the system. As previously stated, the blanking pulses and the horizontal and vertical synchronizing (sync) pulses are amplified in the various stages along with the video information. The sync separator, automatic gain control, and sweep circuits are virtually the same in color receivers as in monochrome receivers.

The detected composite video signal (containing synchronization pulses, blanking pulses, and video) is applied to the control grid or cathode (depending on phase) of the picture


7875 Hz
7875 Hz
7875 Hz
7875 Hz
TO VIDEO AMPLIFIERS AND OUTPUT STAGE
COMPOSITE VIDEO
FROM VIDEO DETECTOR
SYNC SEPARATOR (CLIPPER) STAGE
HIGH PASS FILTER (15,750 Hz) DIFFERENTIATOR
FREQUENCY COMPARING CIRCUIT (PHASE DETECTOR)
HORIZONTAL OSCILLATOR (15,750 Hz)
HORIZONTAL DISCHARGE STAGE
HORIZONTAL OUTPUT STAGE
TO HORIZONTAL DEFLECTION COILS
SAWTOOTH CURRENT 15,750 Hz
VERTICAL & HORIZONTAL SYNC PULSES
D-C CONTROL
REACTANCE STAGE (AFC)
VERTICAL OSCILLATOR
LOW-PASS FILTER (60 Hz) INTEGRATOR
AMPLIFIERS, SHAPING CIRCUITS, PHASE INVERTER (AS NEEDED)
DEFLECTION VOLTAGE STAGE
VERTICAL OUTPUT STAGE
TO VERTICAL DEFLECTION COILS
SAWTOOTH CURRENT 60 Hz
30 Hz
30 Hz
30 Hz

7.104

Figure 12-46.—Block diagram of synchronizing circuits.

tube. The video information intensity modulates the scanning electron beam, producing varying degrees of black through white information on the screen. The blanking pulses cut the picture tube off to prevent a visual indication of retrace. The sync pulses are present but have no effect since they are present during the time the picture tube is cut off and only drive the tube beyond cutoff.

After detection and amplification, the composite video signal is also fed to a sync separation or clipper stage. The vertical and horizontal sync signals are removed from the composite video signal and filtered. Following this, the pulses are amplified and reshaped according to the needs of the synchronization and sweep systems. A block diagram of the synchronization circuits is shown in figure 12-46 with the associated pulse waveforms.

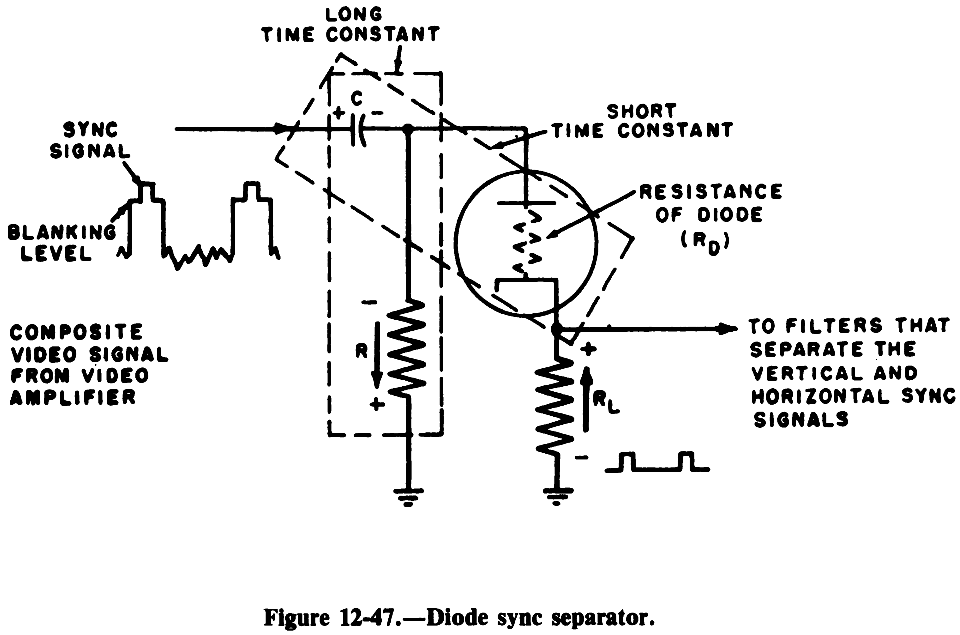
The horizontal sync signal fires the horizontal oscillator at exactly the right instant to maintain the proper synchronization between the horizontal sweep in the receiver picture tube and the horizontal sweep in the transmitter camera tube. The output of the horizontal oscillator is formed into a sawtooth waveform. It is then amplified and applied to the horizontal deflection coils.

The vertical sync signal fires the vertical oscillator at the right instant to maintain the proper synchronization between the vertical sweep in the receiver picture tube and the vertical sweep in the transmitter camera tube. As in the case of the horizontal oscillator output, the vertical oscillator output is formed into a sawtooth wave (modified into a trapezoidal form). It is then amplified and applied to the vertical deflection coil.

SYNC SEPARATORS

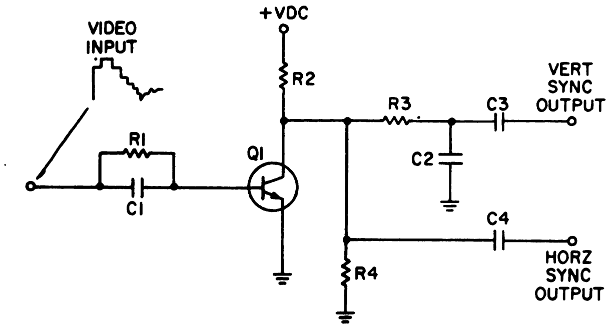
Sync separation, or sync clipping, may be accomplished by the use of circuits employing tubes or transistors. A simplified circuit of a diode sync separator is shown in figure 12-47. During the time the sync voltage is applied to the input, the diode plate is positive with respect to the cathode, and capacitor C is charged through the low resistance of the conducting diode. Between pulses, capacitor C discharges through R and thus maintains a negative bias between plate and ground. This cuts off all signals up to the blanking level. The bias is maintained at approximately the blanking level, and only the sync signal causes pulses of current to flow through Rl, across which the output is taken.

The output pulses consist of the horizontal sync pulses, the equalizing pulses, and the serrated vertical sync pulses. These pulses are fed to filter



7.105

Figure 12-47.—Diode sync separator.



244.205

Figure 12-48.—Transistor sync separator.

circuits that separate the vertical sync pulses from the horizontal sync pulses.

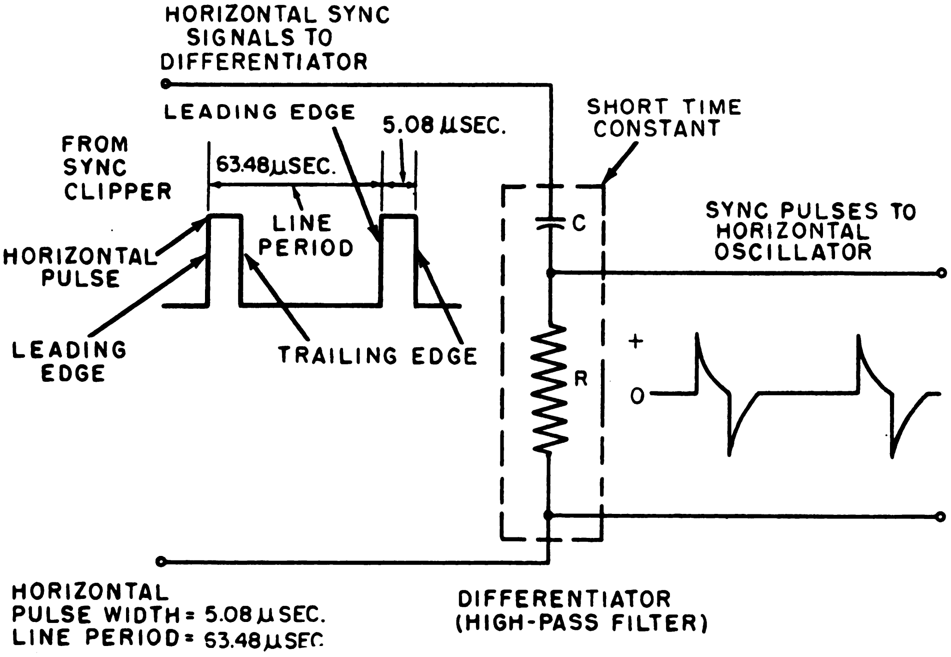
The simple diode separator is easily converted into a transistor sync separator. This is possible because the transistor-input terminals (base-emitter terminals) are actually a diode. The transistor merely adds gain to the basic diode sync separator. Figure 12-48 shows a simplified transistor sync separator.

The problems involved in removing (sync clipping) the sync signals from the composite signal, and in amplifying, separating, and using those signals to control the horizontal and vertical oscillators are treated only in a general way in this section. There are many methods of solving these problems, and therefore a detailed treatment of each method is not possible in this RTM.

Because the repetition rate of the vertical sync pulses is 60 pulses per second and that of the horizontal sync pulses is 15,750 pulses per second, they can be separated by filters.

One filter, the high-pass filter, is used to pass and shape the trigger voltages for the horizontal oscillator (multivibrator or blocking oscillator) as shown in figure 12-49. The circuit in this figure has a short time constant with respect to the period (width) of the horizontal pulse. The output signal is developed across R.

The leading edge of the square-wave input pulse causes a rapid charge of C through R. The trailing edge causes an equally rapid discharge of



7.106

Figure 12-49.—High-pass filter for horizontal sync.

C through R. The flow of charge and discharge currents through R causes the sharp spikes of output voltage, as shown in figure 12-49. Only one spike in each pair (for example, the positive spike) is needed to trigger the horizontal oscillator. The other spike of the pair occurs at a time when the oscillator is insensitive to triggering pulses.

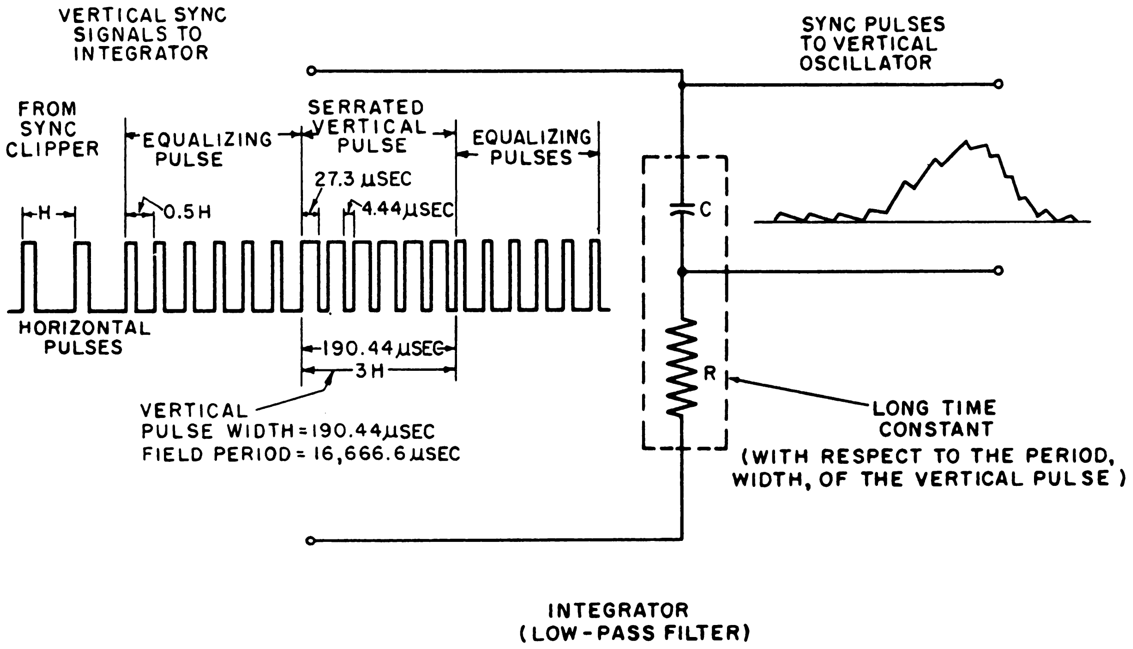
The low-pass filter used to pass and shape the trigger voltages for the vertical oscillator (a multivibrator or blocking oscillator) is shown in figure 12-50. The RC time constant is long with respect to the width of each serration in the vertical pulse. Because of the long time constant in the integrator circuit, C does not have time to discharge during the interval between serrations. However, the RC time constant is short compared to the period of the combined vertical serrated pulses. Thus, C charges up to the peak value during the time the vertical serrated pulse is applied (190.44 μsec in the figure) and dicharges to zero before the next horizontal pulse arrives.

The circuit is relatively insensitive to the longer, low-repetition-rate pulses that control the vertical oscillator. The reason is clear when you note that the time constant (with respect to the width of each horizontal pulse) of the differentiator circuit is short and the output is taken across the resistor.

Because of the long time constant (with respect to the width of each horizontal pulse) of the integrator circuit, the horizontal pulses have very little effect, and the equalizing pulses have even less effect. The only pulse that produces a useful output is the serrated vertical pulse. Sixty of these pulses occur each second, 30 for each of the two fields. The vertical pulses are serrated to provide the triggering action for the horizontal oscillator during the vertical retrace period.

SWEEP CIRCUITS

After being separated and shaped, the horizontal and vertical sync pulses are applied to the vertical sweep oscillators, respectively, so they may be triggered at the correct instant to synchronize the receiver with the transmitter. Both


VERTICAL SYNC SIGNALS TO INTEGRATOR
SYNC PULSES TO VERTICAL OSCILLATOR
FROM SYNC CLIPPER
EQUALIZING PULSE
SERRATED VERTICAL PULSE
EQUALIZING PULSES
27.3 µSEC
H
0.5 H
4.44µSEC
C
HORIZONTAL PULSES
190.44µSEC
3 H
R
VERTICAL PULSE WIDTH = 190.44µSEC
FIELD PERIOD = 16,666.6µSEC
LONG TIME CONSTANT (WITH RESPECT TO THE PERIOD, WIDTH, OF THE VERTICAL PULSE)
INTEGRATOR (LOW-PASS FILTER)

7.107

Figure 12-50.—Low-pass filter for vertical sync pulses.

the vertical and horizontal sweep oscillators, when fed into the correct circuits, produce current sawtooth waveforms.

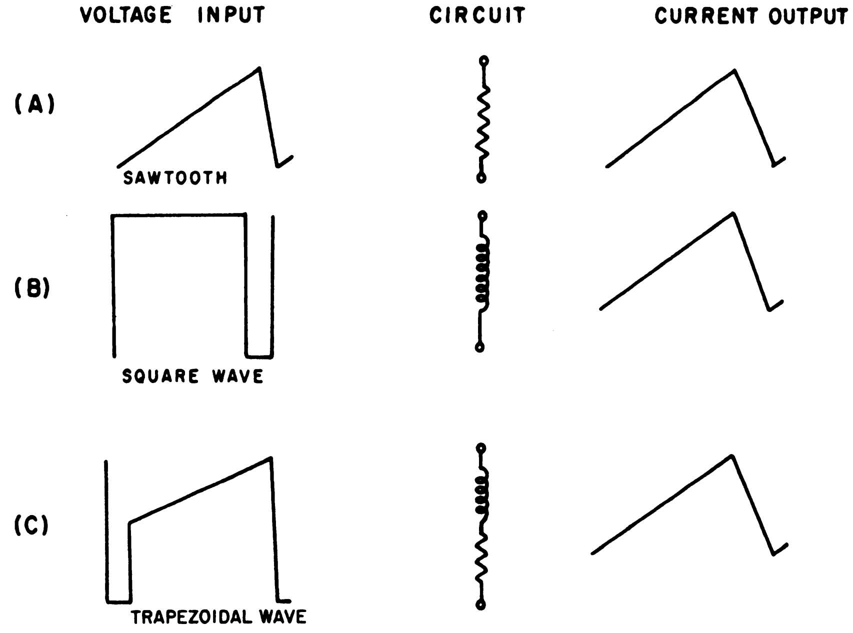
The sawtooth waveforms produced by the horizontal sweep oscillator are amplified and applied to the picture tube in a manner that will cause the electron beam to be deflected (swept) horizontally across the face of the tube. Likewise, the waveforms produced by the vertical sweep oscillator cause the electron beam to be deflected from the top to the bottom of the picture tube. Multivibrators and blocking oscillators are two types of resistance-capacitance oscillators commonly used in the sweep circuits (vertical and horizontal) of television receivers.

In electromagnetic deflection systems, the driving force in the picture tube is a magnetic field. To develop such a field, a sawtooth deflection current is required. Further, because of the inductive action in the output state of a tube-type vertical-output amplifier, a trapezoidal waveform is required to produce this sawtooth of current. This is illustrated in figure 12-51. To produce a sawtooth of current through an inductive circuit, a square wave of voltage must be applied (B). To produce a sawtooth of current through a resistive circuit, a sawtooth of voltage must be applied (A). To produce a sawtooth of current through an inductive-resistive circuit, both a sawtooth and square wave (trapezoidal wave) must be applied (C).

Vertical Sweep

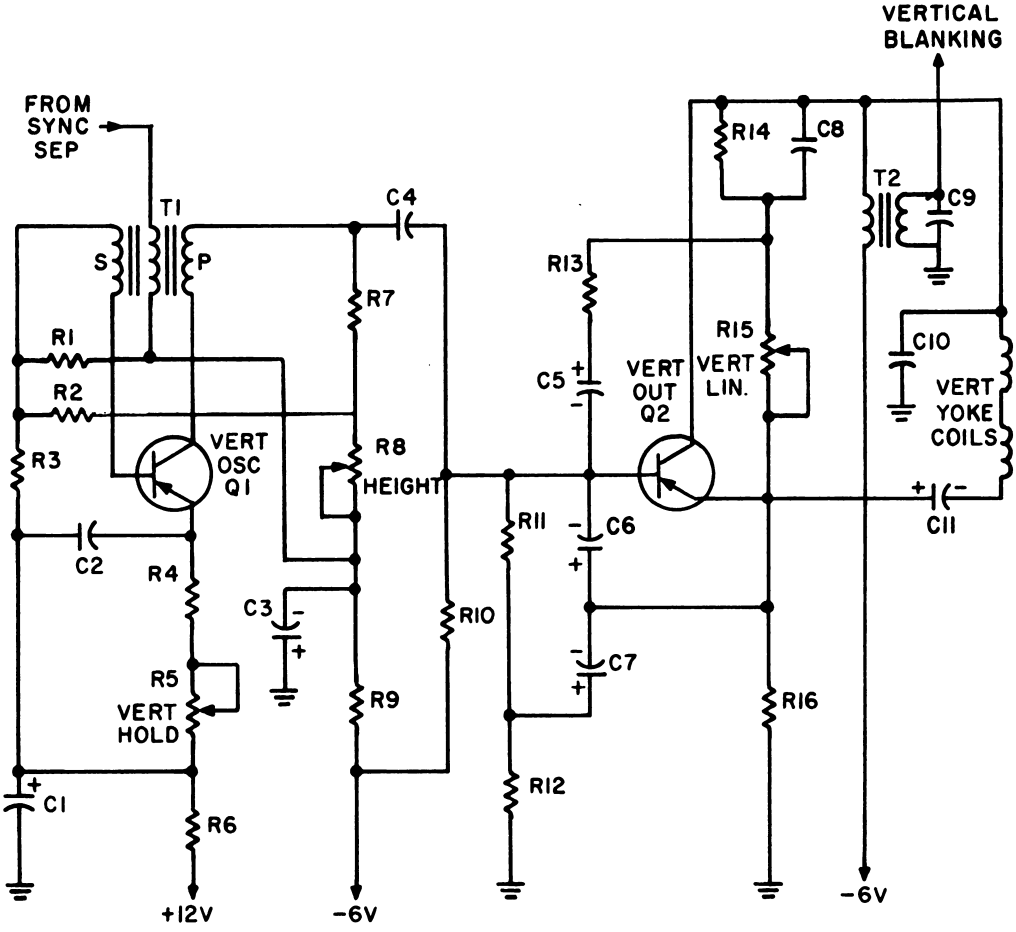
The vertical sweep circuit (figure 12-52) produces a current which moves the electron beam of the picture tube from the top to the bottom. You should note that when transistors are used for the vertical and horizontal output amplifiers, the input wave to the output transistor is generally not trapezoidal but is close to a sawtooth.

The vertical oscillator (Q1) shown in figure 12-52 is a conventional blocking oscillator. The signal from this oscillator is fed to the vertical output stage (Q2) and on to the series-connected vertical yoke coils. Oscillator frequency is determined by the RC time of C2, R4, and R5. The height control (R8) varies the collector bias



40.229

Figure 12-51.—Trapezoidal waveform.



244.206

Figure 12-52.—Vertical sweep section.

voltage, thus changing the amplitude of the output signal. Without compensation, this could change oscillator frequency since it affects the charging capacitor by changing the amount of charge. Hence, a compensating network is included to prevent this from occurring. R1 is connected from the negative six-volt supply to the secondary of winding T1, shunting both R8 and R2. The effect of this network is to change the forward bias on the oscillator so that the frequency is shifted in the opposite direction to compensate for any shift caused by the height adjustment.

The oscillator signal is coupled to the base of the output stage through C4. Forward bias for Q2 is provided by the voltage divider network (R10, R11, and R12) in the base circuit. Both emitter and collector currents normally flow. The positive pulse from the vertical oscillator opposes this forward bias and abruptly reduces the emitter-collector current. This period of abrupt current drop is the vertical retrace time and lasts for the duration of the oscillator pulse. C5, C6, and C8 combine to form the sawtooth wave for the vertical trace period. R15, in series with C8, forms a waveshaping feedback circuit between the emitter and collector of Q2. C5 and R13 perform the same function between the output and the base.

Vertical output transformer T2 is a voltage step-up device with the secondary providing sufficient voltage for vertical retrace blanking. C9 is connected from the secondary to ground to prevent any horizontal pulses from distorting the vertical output. The vertical yoke coils, which are actually the collector ac load, are returned to the emitter of Q2 through C11 to isolate the yoke from dc. C10, connected from the collector to ground, provides further filtering.

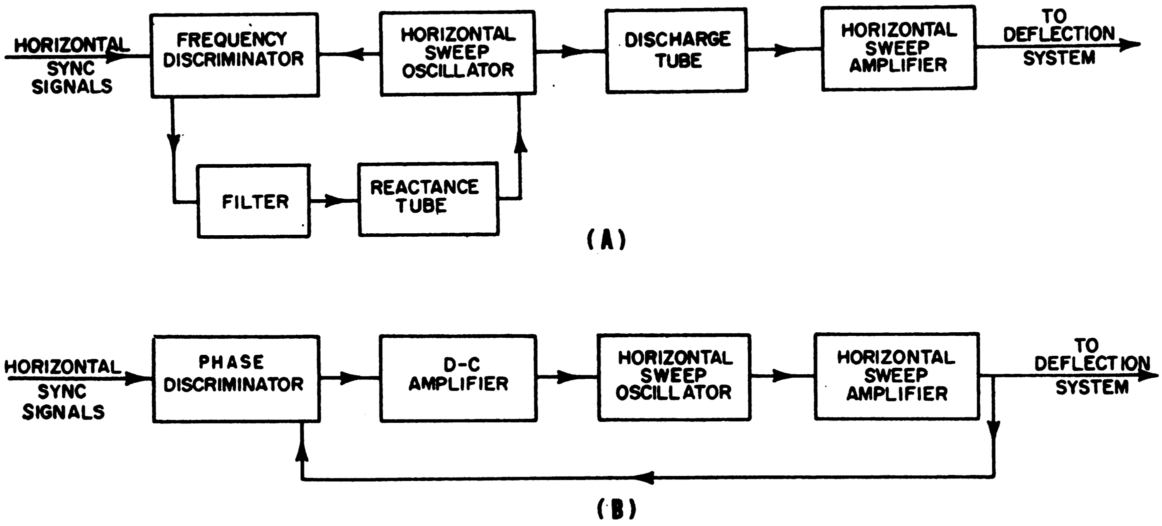
Automatic Frequency Control (AFC)

The use of incoming sync pulses to trigger and control the vertical and horizontal sweep oscillators is the simplest, most economical, and most direct method of controlling the motion of the electron beam in a television. This simple, direct system would be satisfactory if it were not for the presence of noise pulses that may cause the oscillators to fire at the wrong time. When the vertical oscillator fires at the wrong time, the picture is not properly synchronized vertically. The picture bounces, or moves in jumps upward or downward across the screen. When the horizontal oscillator fires at the wrong time, the picture is not properly synchronized horizontally. The picture tears or becomes streaked, giving the appearance that the picture is jumbled.

Although noise pulses may affect the operation of both the vertical and the horizontal oscillators, a far worse effect is felt by the horizontal oscillator. The long time constant of the vertical filter makes it insensitive to the short bursts of noise energy, and the effect on the vertical oscillator is not generally objectionable. In closed circuit TV, noise from electrical machinery can be just as destructive as atmospheric noise in a conventional home TV system.

The short time constant of the filter that feeds the sync pulses to the horizontal oscillator permits the passage of short bursts of noise energy. Consequently, it is necessary to employ a control circuit that effectively isolates the horizontal oscillator from the effects of noise pulses, and at the same time permits the sync pulses to assume control.

Two systems that isolate the horizontal sweep oscillator from the effects of noise bursts are shown in the block diagrams of figure 12-53. In the system shown in part (A), two signals are applied to the frequency discriminator. They are horizontal sync signals and horizontal sweep oscillator signals. The frequency discriminator compares the frequency (or phase) of these signals and produces an output dc voltage that depends on the difference between the frequencies (or phase) of the two signals. The output voltage, normally varying at a relatively slow rate, is fed



7.111

Figure 12-53.—Systems of horizontal sync control.

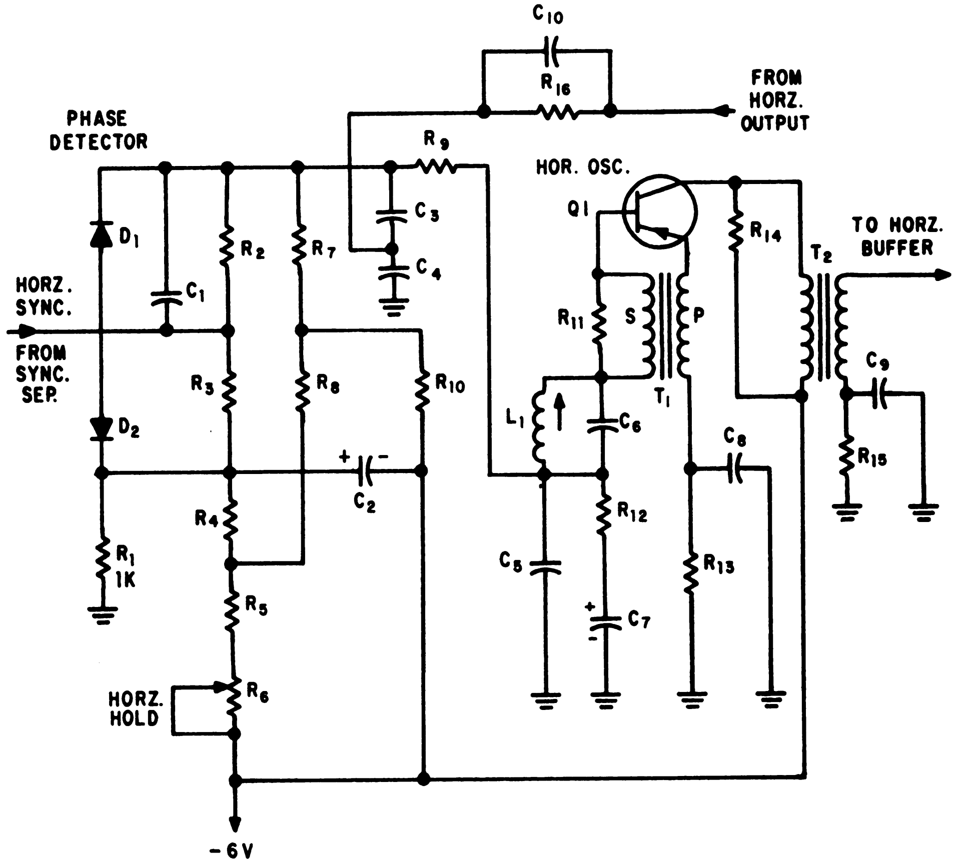
via a low-pass filter to the grid of the reactance tube. This tube functions in such a manner that its output changes the frequency of the horizontal sweep oscillator to maintain its frequency exactly the same as that of the incoming horizontal sync pulses.

The second method of isolating the horizontal sweep oscillator from noise bursts is shown in figure 12-53(B). As in the previous system, a frequency (or phase) discriminator is used. It compares the sync-signal input from the filter or sync amplifier with the input feed-back from the horizontal sweep amplifier and produces a dc output that is proportional to that difference. The manner in which this dc output is amplified and used causes the frequency of the horizontal sweep oscillator to lock in step with the incoming sync signals.

Horizontal Sweep

In general, the same basic types of deflection oscillators found in the vertical deflection system are also used in the horizontal system. These are the blocking oscillator and the multivibrator types that employ both tubes and transistors.

Figure 12-54 is a simplified schematic diagram of the phase detector and oscillator portion of the horizontal sweep section of a transistorized TV receiver. The phase detector samples a feedback signal from the horizontal output stage and compares its phase with the incoming horizontal sync pulses. Any phase difference results in an appropriate dc voltage from the phase detector being applied to the oscillator. This signal then causes the oscillator to change its frequency.



244.207

Figure 12-54.—Horizontal Sweep (Part A).

When the pulses are in phase, the outputs from D1 and D2 are equal and opposite, thus no dc control voltage is produced for the base of the oscillator. When the oscillator frequency is low or lagging the sync, D1 conducts more heavily than D2, producing a positive control voltage at the output. This positive voltage, applied to the base of Q1, increases the frequency of oscillations. When the frequency of the oscillator is high or leading the sync, D2 conducts more heavily, producing a negative control voltage which lowers the frequency of the oscillator.

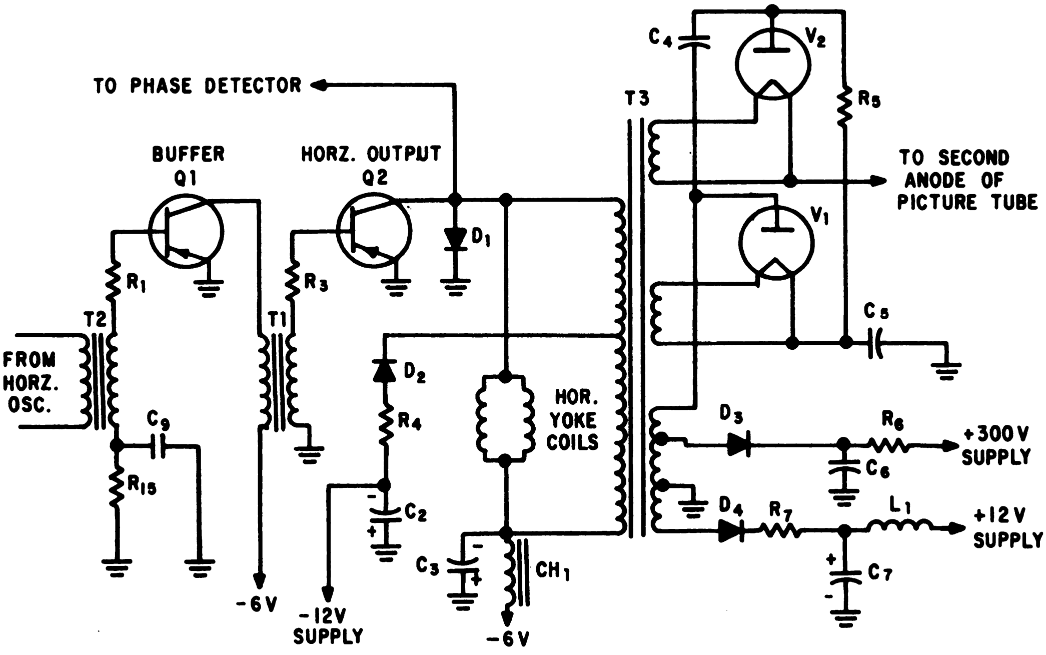
The horizontal oscillator, Q1, is a blocking oscillator that operates similar to the one in the vertical section. Transformer T1 is the blocking-oscillator transformer, and L1 is a stabilizer coil.

Stabilizing coil L1 is in series with the secondary of T1 and is shunted by C6. When an abrupt current change through the coil occurs due to oscillator action, C6 discharges through the coil. The resulting magnetic field around the coil induces a voltage that recharges the capacitor, but to a lower level than previously charged. Thus, the oscillations are damped out. The timing of this ringing action is adjustable to the point where it helps fire the oscillator at a constant rate, thus providing a degree of stability.

Horizontal hold control R6 establishes the bias on the base of Q1 to bring the oscillator within control range of the phase detector. Since the setting of R6 can affect the balance of the phase detector, isolating and compensating resistors R4, R7, R8, and R10 are incorporated to minimize this effect. The horizontal output pulse that is fed back to the phase detector is shaped into a sawtooth wave by C4, C10, and R16.

The balance of the horizontal sweep circuits (buffer, horizontal output, and high voltage) are shown in figure 12-55. The positive output pulse of the oscillator is inverted by interstage transformer T2 and applied to the base of Q1 as a negative pulse. The buffer is normally cut off since there is no forward bias from the base to emitter.

The negative pulse at the base of the buffer amplifier drives the stage into conduction. RC network C9 and R15, however, develops a base bias from the signal current which permits



244.208

Figure 12-55.—Horizontal sweep (Part B) and high voltage.

conduction only on the peaks of the pulses. Since a common emitter circuit is used, a positive pulse appears at the collector. The positive signal from the buffer is transformer-coupled through T1 to the base of the horizontal output transistor Q2.

The output transistor is a special power-type transistor capable of handling the relatively high-power requirements of the stage. At the collector, a positive horizontal sweep pulse appears and is directly coupled to the horizontal yoke coils connected in parallel. The horizontal pulse causes a relatively linear sawtooth current in the yoke coils. Yoke damping action is provided by diode D1 which dampens any self-resonant oscillations of the yoke.

A tap on the primary of horizontal output transformer T3 is used to develop a −12 volt supply through diode D2. Two taps on the secondary of the same transformer provide +12- and +300-volt power supplies through their respective diode rectifiers and filters.

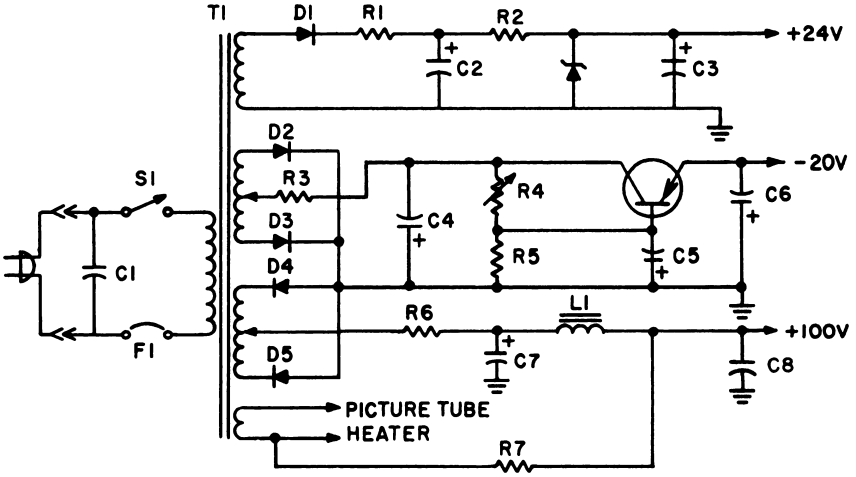
When the horizontal output transistor is conducting, collector current is drawn through the primary of T3, and the collector voltage declines from −6 volts in a positive direction, producing a positive horizontal sweep pulse. The heavy current flow through the transformer primary causes high peak-voltage pulses to be developed across the high-impedance secondary winding. These pulses are applied to the plate of the first high-voltage rectifier, V1. The rectifier current charges C5 to approximately 5,000 volts. This voltage is applied to the plate of the second rectifier, V2, through R5. Capacitor C4 also couples the high-voltage pulse from the transformer secondary to the plate of V2, thus adding to the high dc voltage applied through R5. As a result, approximately 10,000 volts appear at the filament of V2. This is the high voltage that is applied to the second anode of the picture tube (kinescope). Voltages up to 30 kV are found in color TV high-voltage systems.

TV POWER SUPPLIES

Because of the high-voltage requirements of the CRT, TV receivers employ two power supplies—high voltage and low voltage. The high-voltage section was discussed in the previous section. A typical transistorized low-voltage supply will now be discussed.

New solid-state TV receivers utilize both low-voltage and high-voltage transistors. This requires a large assortment of voltages. Since transistors are low-impedance devices, they work best when driven by voltages from low-output-impedance supplies.

A power supply that provides multiple low-impedance output voltages is shown in figure 12-56. The −20 and +24 output voltages drive



244.209

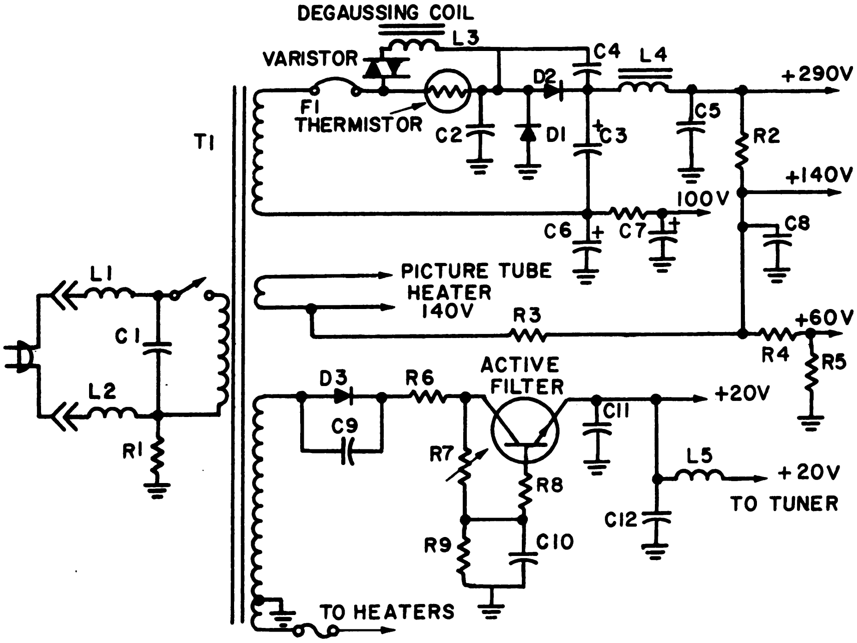
Figure 12-56.—Black and white, solid state power supply.

most of the low-level stages in the set. A Zener regulator is used for the +24 volt supply, and an active filter is employed in the −20 volt supply. The +100 volt output services the output stages of the following sections: video, vertical, horizontal, and audio. Note the wiring arrangement of the two full-wave rectifiers. This is done in some receivers so that part of the diode can be physically connected to ground. The ground is then used as a heat sink, eliminating the need for an insulator between ground and the rectifier body.

Generally speaking, color TV power supplies are slightly larger and more complex than those found in black and white sets. This is due in part to the power required by the extra circuits in the color sets and the automatic degaussers in the B+ line.

Figure 12-57 shows a typical power supply used in large-screen color TV receivers. This type of power supply, with its numerous output voltages, feeds both transistors and tubes. Most of the transistors receive their power from the +20 volts developed by the active filter. After a little extra filtering, this same +20 volts is sent to the tuner. R7 is used to adjust this output. All of the tube heater filaments, except the picture tube, receive their power from the same output winding that provides the +20 volt outputs. The picture tube heater is on a separate winding that is biased to +140 volts to prevent cathode to heater shorts.

The +290-volt B+ supply has a degaussing circuit in series with it. A thermistor and varistor control the current in the degaussing coil. As the circuit warms up, the thermistor decreases in resistance and the varistor increases in resistance. The net result is a surge of current through the degaussing coil for a few seconds before the set warms up. Very little current then flows through the coil during normal receiver operation. The +290-volt supply uses a half-wave voltage doubler. Capacitors C2 and C4 are across the diodes for transient protection. This feature gives the diodes a much longer life.



244.210

Figure 12-57.—Color, solid state power supply.

SUMMARY

Television can simply be defined as the transmission and reception of visual images by means of electrical signals. The main problem you will encounter with TV transmission is to have the receiver or monitor in sync with the camera. In this chapter, you have been presented with a discussion centering around the basic block diagrams found in the television camera and receiver. In many military applications, these blocks will be incomplete or have special additions depending upon which one of the various military applications is used. As each new aircraft is introduced into the Navy's inventory, more and more video or television indicators are used.

CHAPTER 13

AVIONICS MAINTENANCE

Radar maintenance is more exacting and complicated than the maintenance of other electronic equipment. For example, to some degree, you can determine whether or not a radio receiver is operating in a satisfactory manner by listening to the tone and observing how much you must advance the gain control to get sufficient volume.

You cannot test radar system performance through observation. If you rely on visual observation to judge the range capability and other data accuracy, you will not be accurate. Your observation might be totally useless. To determine whether or not a radar set is operating at peak efficiency, you should use performance testing. As an AQ, you must use the correct techniques when checking a radar set. These will ensure that the set is operating properly.

Recent radar systems are provided with self-testing features called built-in-tests (BITs). Typical tests will verify overall system target detection capability, angle tracking capability, and missile computation accuracy (for missile control). Test equipment is not required for this type of testing since the BIT box is used to "read out" the results of the specific tests. This type of testing also allows the operator to perform system tests while airborne. The results of the inflight tests will often aid you to pinpoint any trouble that may be encountered.

While troubleshooting wiring problems, or problems with coaxial cable, the AQ often discovers the problem to be in a wire or coax that runs the entire length of the aircraft or at least a large portion of it. To aid in troubleshooting and pinpointing the exact location of the problem, you may use a time-domain reflectometer (TDR).

MAJOR UNIT CHECKS

In this chapter, you are presented with a discussion of the most frequent and difficult radar maintenance problems. An intermittent trouble is probably the most aggravating and irritating problem you face as an AQ. Equipment always seems to operate properly while under observation, only to malfunction as soon as you turn your back. There is no single method for resolving this difficulty. The procedure to be used depends on the individual situation—the technician, the equipment, the available information, and the peculiarities of the installation. A thorough knowledge of the operation of the equipment and an understanding of the most common causes of intermittent troubles should help in troubleshooting intermittent problems.

Some common causes of intermittent troubles are poor electrical connections, poor solder joints, leaky capacitors, arcing, broken terminal boards or printed circuits boards, fused conducting strips, and mechanical vibration. Vibration is usually associated with one or more of the causes just mentioned. It may be a basic cause or a contributing factor; therefore, it should always be investigated early in the troubleshooting procedure. If equipment seems to operate properly after a visual inspection fails to reveal the cause of the intermittent trouble, vibrate the equipment by tapping or jiggling while watching it. If this fails to produce meaningful indications, methodical and patient troubleshooting procedures must be followed.

A description of an entire radar testing procedure would be too lengthy. The checks, measurements, and adjustments receiving particular attention are those of the transmitter and receiver. These units seem to be the most difficult for the AQ to maintain properly. The power supply, synchronizer, indicator, and antenna are also discussed but not in great detail.

POWER SUPPLY

The power supplies most often used in avionics equipment are either regulated or unregulated. An unregulated power supply usually provides filtered but unregulated low B+ (under 300 volts) or high B+ (over 300 volts) and, in some cases, relay-operating power. The regulated power supply consists of an unregulated supply and the associated circuitry necessary to regulate the B+ output. You should refer to NEETS, Module 7 for a more detailed discussion of power supply operation.

Power supplies used to provide the dc voltage source for operation of electronic equipments are of various types, such as half-wave and full-wave rectifiers. The type of circuitry used for a particular application depends on such factors as current and voltage load requirements, available space, weight limitations, and degree of voltage regulation required. Electronic systems are generally complex. They contain one or more power supplies which provide several voltage outputs. The performance of these equipment depends upon proper operation of the power supplies. For this reason, power supply tests are included in the preventive maintenance test procedures prepared for most equipment. Many equipments are provided with easily accessible test points for ease in performing these tests. The most common type of power supply test is a simple voltage reading taken with the equipment in operation.

In order to operate radar equipment, various dc voltages are required. The transmitter requires a high voltage source capable of delivering a large current for short intervals of time. The regulation or ripple content of this voltage is not critical. The cathode-ray tube (CRT) requires a high accelerating voltage which is usually easy to regulate because the small load results in a low current drain. The plate voltage supply for the receiver and the indicator sweep circuits requires a source of good regulation and very little ripple. Voltages are also required for relays, blower motors, antenna control motors, and other parts of the radar system. Combinations of vacuum tubes, rectifiers, transformers, and voltage dividers are used to provide these different voltages.

Power supplies of various types occur throughout the radar system because it is impractical to install all of them in a central location. In some equipments the power supply may lose its identity as a separate unit. However, its function is still performed and must be tested and maintained at its rated performance.

SYNCHRONIZER

The synchronizer unit controls or synchronizes the entire radar set. The timing pulses and other signal voltages generated by this unit must be checked frequently, and they must be adjusted if necessary.

NOTE: Not all radars on which an AQ may work will have a unit called a synchronizer, nor will there be a single unit which synchronizes the entire radar set. Several units may be used to provide synchronization of the system.

The pulse-repetition frequency (PRF) will have several PRF selections, depending on the range or mode selected. In addition to establishing the PRF, the synchronizer usually produces the following signals—range sweep voltages, range marker signals, range strobe signals, and intensity gates. These signals and the circuits used to generate them were discussed in chapter 7.

Extensive use of an oscilloscope is required when making checks and alignments of the synchronizer since the signals and voltages previously mentioned require precise time measurement and, in some cases, measurement of signal amplitude. Although synchronizer checks must be made with great care and precision, they are relatively simple when proper procedures are followed. The operation of the oscilloscope is not difficult. The problem is in proper interpretation of observed waveforms.

If you find that adjustment or alignment is required, you must rigidly follow the currently approved alignment procedures as described in the appropriate maintenance instructions manual (MIM). Synchronizer alignment is normally accomplished using a step-by-step procedure, with the steps being performed in a specific sequence.

Each step depends on the one before it. You must NOT rely on memory when making alignments.

INDICATOR

Both the pilot and navigator depend on information displayed on the indicator to fly the aircraft into the proper position for dropping a bomb or releasing a missile. If what they observe on the face of the indicator is not properly positioned, or if information is missing, mission effectiveness could be reduced or fail completely. In some cases, the aircraft and the lives of the crew could be placed in grave danger.

Today's airborne weapons systems radars use many different types of indicators. A typical indicator is illustrated in figure 13-1. Some or all of the following information may be displayed on this indicator:

1. Target range and bearing.
2. Artificial horizon.
3. Antenna position.
4. Steering information (target relative position).
5. Range rate and range to go.
6. Warning signal lights and various reference lines scribed into the face of the indicator.

A portion of the above information is written on the face of the indicator by the electron gun(s) and must be positioned properly in order to be of value to the operator. The adjustments required during an alignment check are easy to perform, but they must be made exactly as prescribed in the alignment procedures.

Many of the positioning voltage adjustments are similar to the oscilloscope display voltage adjustments. The main difference is that the position of each displayed item, such as artificial horizon and range circle, depends on separate vertical and horizontal centering adjustments. One adjustment worthy of special attention is made to steering information deflection sensitivity. Steering information is derived from the antenna's position. Therefore, for a given amount of antenna displacement from center, the steering information must be deflected by the proper amount in order for the pilot to successfully track the target. If the sensitivity is too great, the pilot will have trouble making a smooth tracking run. If the sensitivity is too low, steering information will be sluggish and lag far behind the actual position of the antenna.

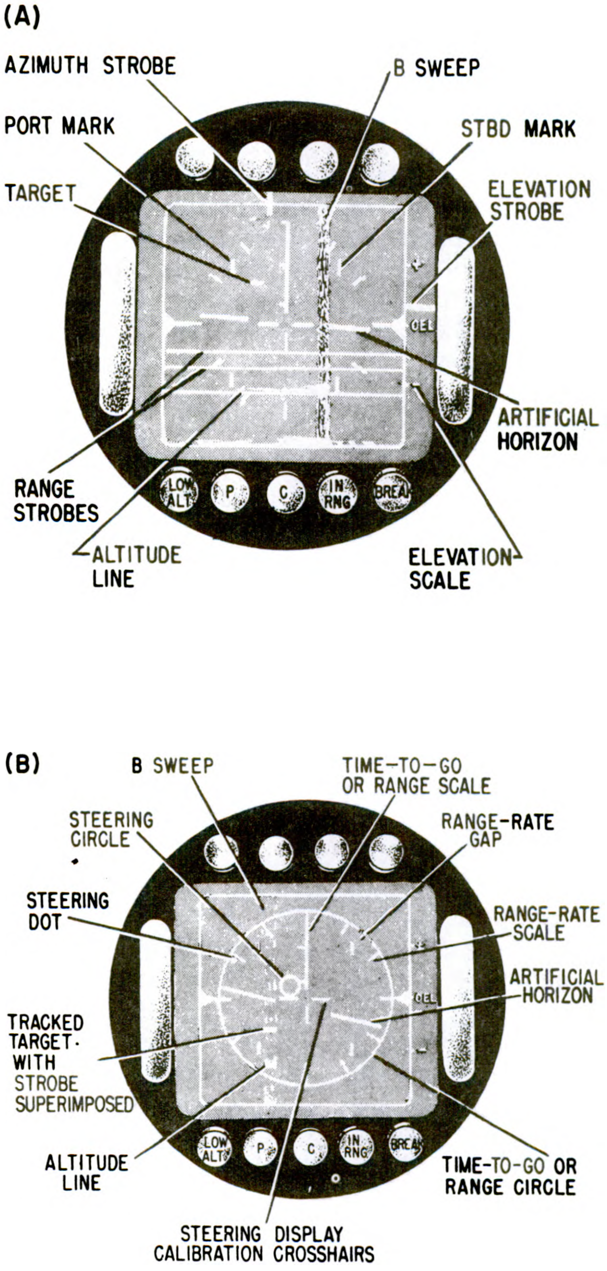


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Figure 13-1.—Typical indicator display, (A) Search; (B) track.

Intensity should be set so the trace is just below the threshold of visibility as it sweeps back and forth. Then, any target return is easily discernible. Once the intensity is properly adjusted, the various strobes (range markers, cursors, artificial-horizon-bars, and so forth) should be set at a comfortable viewing level.

NOTE: Some indicators are equipped with viewing hoods. In such a case, intensity is adjusted with the hood in place with no external light striking the face of the indicator.

Focus adjustments should be made so the presentations are sharply defined. If the presentation does not remain sharp at all positions on the face of the indicator, the astigmatism control must be adjusted (along with the focus control) until the presentation is sharp and clear.

Where the indication is positioned in azimuth or elevation by the position of the control handle or the antenna, you should make sure the indication moves an equal amount on both sides of center. The indication should be centered when the antenna is centered.

All indicator lamps used to illuminate control panels, range indications, and warnings should be checked. When any are burned out, they should be replaced.

Two items that discourage an operator are range circles that are not round and targets that are incorrectly positioned on the B trace (in the case of a B-type scan presentation). If circles are not properly rounded, the range indication is distorted and may confuse the operator. The other item relates to adjustment of the B-trace sweep length as presented on the indicator. If the B trace is not of correct length, the target range will be wrong. For instance, if a radar is on the 50-mile range, the B- trace length represents 50 miles and should sweep from the bottom of the scope to the top. If operation is on the 50-mile scale, a target at an actual range of 25 miles should appear halfway up the sweep (at the center of the scope). If the B trace is improperly adjusted, the target will appear at a range other than 25 miles and possibly cause confusion to the operator.

Remember, in order to receive maximum advantage from the use of a radar, the indicator must present all information in the best possible form. If this is not done, the operator may lose confidence in the equipment, and failure of the mission may result.

ANTENNA

The antenna operates as part of a servosystem. Therefore, most antenna functions are checked along with other portions of the radar system. Alignment of a typical antenna servosystem is described in chapter 3.

TRANSMITTER

The measurement of frequencies which are used in radar operation falls into two general categories—transmitter frequency and receiver frequency.

For the transmitter operation of any given radar system, a range (band) of frequencies is assigned for that system. Therefore, the transmitter must operate within this band of assigned frequencies if normal operation is to be expected. Transmitter operation is restricted to a certain range of frequencies for the following reasons:

1. The associated waveguide tuning adjustments cover only a limited range of frequencies.
2. Interference between radars used for different types of services could result if all radars were permitted to operate in the same band. For this reason, airborne E- and F-band and shipboard E- and F-band radars usually operate in different parts of their respective bands.

Radar transmitters may be either fixed in frequency or tunable. Tunable transmitters may be adjusted to any frequency within an operating band. This is a desirable feature when several radars are simultaneously in use in the same area as each one may be tuned to a different frequency to prevent interference. In addition, when jamming is present, a different transmitter frequency may be selected to be free of the jamming signal. Since the operating bands are fairly wide, transmitter frequency tests do not require extreme accuracy.

Frequency Measurements

The transmitted frequency of a microwave radar set is readily measured by using a resonant cavity wavemeter (absorption-type frequency meter), as described in the *Avionics Technician (AQ, AT, AX) 3 & 2*, Part 1, NAVEDTRA 10319.

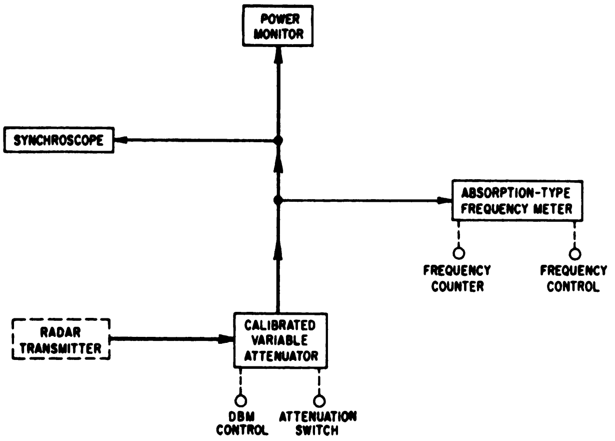

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Figure 13-2.—Power and frequency measurements, block diagram.

When tuned to the frequency of the transmitter, the wavemeter cavity absorbs some of the microwave power. This absorption of power is indicated by a dip on the power monitor's meter.

A convenient method of coupling the radar transmitter to the wavemeter is by coaxial cable. One end of the cable is connected to the radar's directional coupler, while the other end is connected to the wavemeter's input.

Figure 13-2 shows a block diagram of components set up to measure power or frequency. When the frequency meter is tuned, the control knob should be moved slowly. It is possible to tune by the transmitter frequency without knowing it. This is because the absorbed power is detected by a thermistor, which takes a short time to heat and react to the power applied to it.

The resonant frequency of the radar may also be indicated on the synchroscope. The reduction in transmitter power caused by absorption in the resonant cavity is indicated by a decrease in pulse amplitude on the CRT. This dip is usually easier to detect than the dip on the power meter because the scope responds more quickly than the power meter. Final tuning, however, should always be done by the AQ while observing meter indications. Transmitter frequency may also be measured during spectrum observation.

Spectrum observation is accomplished by displaying the magnetron's output signal on a synchroscope. Using this method, the AQ may readily determine visually whether or not the magnetron is operating properly. Figure 13-3

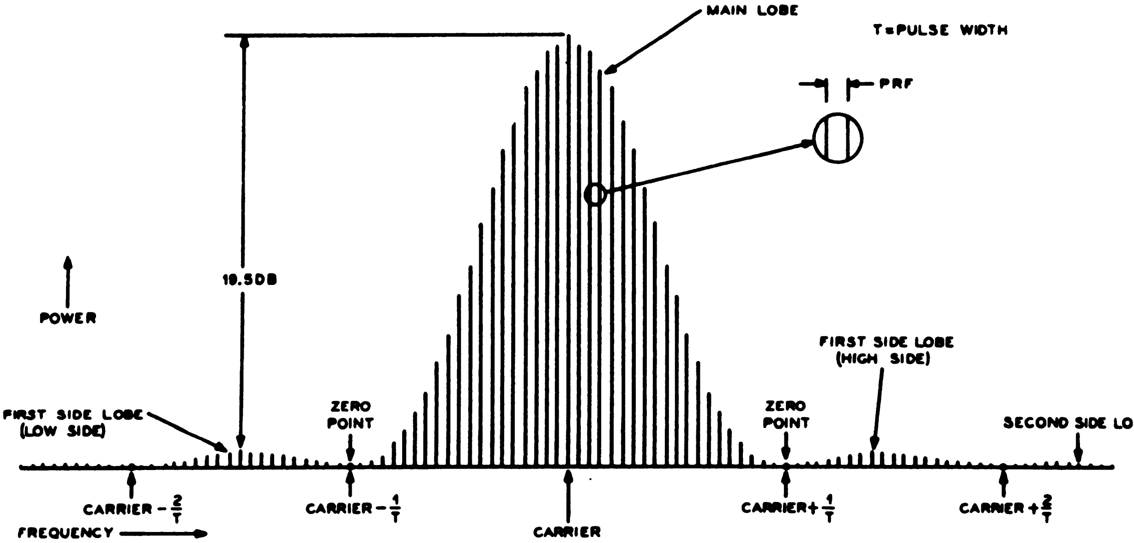

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Figure 13-3.—Ideal spectrum of a pulsed magnetron.

shows an ideal spectrum of a pulsed magnetron. Note the side lobes are very low compared to the main lobe, and the main lobe falls off to zero on each side of the carrier frequency.

Figure 13-4 shows several examples of transmitter spectral displays that are less than ideal. In general, distortion resulting from frequency modulation (figure 13-4(A) and (B)) is far more undesirable than distortion resulting from amplitude modulation (figure 13-4(C)). Both frequency and amplitude modulation may be presented in a spectral display (figure 13-4(D)).

Poor spectra may be caused by a defective magnetron, a mismatch in the RF section (pulling), a pulse of improper shape or amplitude from the modulator (pushing), or reflections from nearby objects (pulling). Firing the transmitter into a dummy load will usually isolate a trouble caused by external influences, such as waveguides, rotating joints, or other reflections.

Figure 13-5 illustrates a spectral display as it would appear on a synchroscope. Note the small break in the base at the center of the display. This is a frequency marker (pip) that is positioned by varying the frequency control on the test set. Since this pip occurs at the test set oscillator frequency, and not at the radar transmitter frequency, the frequency reading on the test set must be corrected by adding or subtracting the IF frequency (commonly 30 MHz). Another method used is to first measure the frequency of the display with the test set oscillator tuned to a frequency above the radar frequency, then measure the frequency of the display with the test set oscillator tuned to a frequency below the radar frequency. Adding the two indicated frequencies together and dividing by 2 will give the true transmitter frequency, even though the IF frequency is unknown.

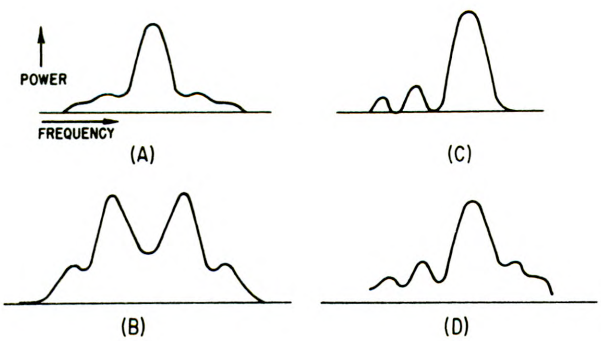

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Figure 13-4.—Magnetron spectral displays showing distortion.

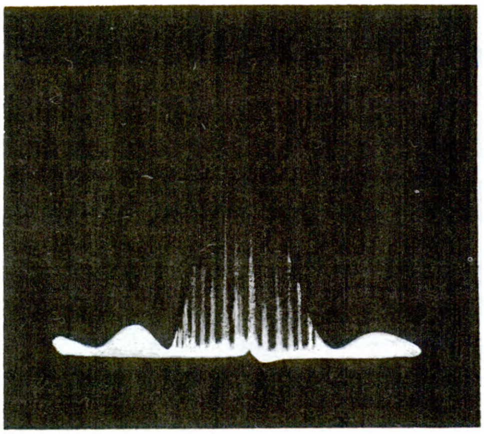

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Figure 13-5.—Spectral display showing frequency meter dip.

Power Measurements

High peak power is desirable in a radar transmitter in order to produce a strong echo at long ranges. Low average power is desirable because it enables transmitter components to be made smaller and more compact with less regard for cooling them. It should be apparent that a low duty cycle is desirable. The relationships of peak power, average power, and duty cycle are described in the *Avionics Technician (AQ, AT, AX) 3 & 2*, Part 1, NAVEDTRA 10319. The peak power a set is capable of developing is primarily a design consideration. Peak power is dependent upon the interrelationship between average power and between pulsewidth and pulse repetition time (or duty cycle). Optimum power performance is attainable in most radar sets by means of a control for adjusting magnetron current. This feature, especially desirable in radars incorporating tunable magnetrons, enables the operator to adjust magnetron current to recommended optimum values.

Power measurements on a radar transmitter can be made by using either of two methods of sampling the power output. One method uses a pickup horn in front of the radar antenna. Placement of the pickup horn in relation to the antenna is extremely critical as air losses must be taken into consideration. A more satisfactory method involves connecting the test set to the radar directional coupler. This avoids the difficulty in measuring or calculating air losses.

When power (in dBm) is read from the test set attenuator dial, power losses must be added to this figure. This is done by adding the attenuation (in dB) of the directional coupler and the loss (in dB) of the coaxial cable to the attenuator dial reading. The cable loss is usually indicated on a tag attached to the cable, and usual values are about 1 dB per foot of coaxial cable. The loss (in dB) of the directional coupler is found on a tag or nameplate attached to the directional coupler and is usually 20 dB or more.

The following procedure may be used for testing a radar set for average power output. When the test set and radar are warmed up and operating, appropriate connections are made in accordance with the operation instructions for the test set.

NOTE: Two precautions should be observed when connections are made to the test set:

1. Be sure the attenuation controls are set for maximum attenuation to avoid damaging the test set when the power level is too high.

2. Turn the frequency meter off resonance so none of the power will be lost in the resonant cavity.

The attenuation controls are now adjusted to decrease attenuation until the power meter reads 1 milliwatt. The attenuation (in dBm) is read from the attenuator dial. The attenuation of the directional coupler and the coaxial cable are added to this. The total attenuation is indicative of the transmitter power.

Figure 13-6 shows a graph that can be used to convert power in dBm to average power in watts. This can also be accomplished mathematically by solving the equation

$$\text{dBm} = 10 \log \frac{P2}{P1}$$

where dBm is total attenuation, P2 is the unknown output power in milliwatts, and P1 is the 1-milliwatt reference level.

For example, suppose the power measurement of a radar set results in a dial reading of 21 dBm on the test set, the directional coupler is marked 20 dB, and the coaxial cable has an attenuation of 1 dB per foot and is 8 feet long. These values, inserted into the equation, give

$$49 \text{ dBm} = 10 \log \frac{P2}{P1}$$

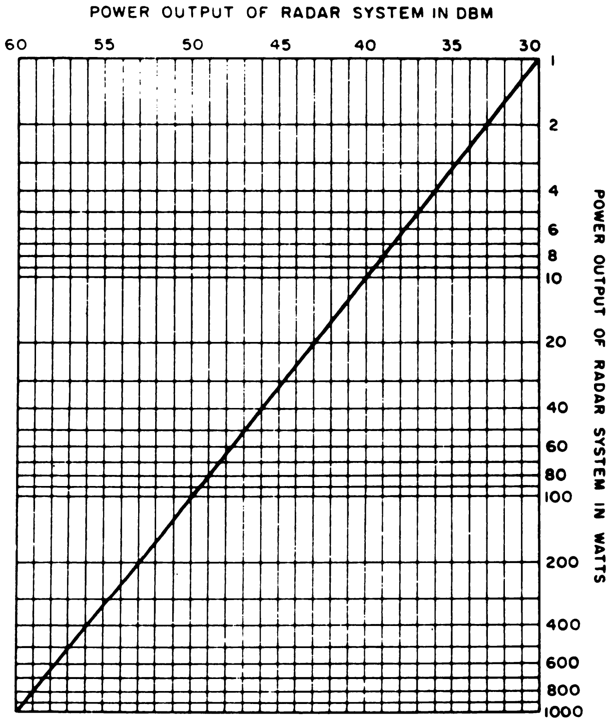

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Figure 13-6.—Conversion of power in dBm to power in watts.

This equation is rearranged and 1 mW (reference power) is substituted for P1. This gives

$$4.9 = \log \frac{P2}{1\ \text{mW}}$$

$$10^{4.9} = \frac{P2}{1\ \text{mW}};\ P2 = 10^{4.9} \times 1\ \text{mW}$$

$$P2 = 10^{0.9} \times 10^{4} \times 1\ \text{mW}$$

$$P2 = 7.94 \times 10^{4}\ \text{mW} = 79400\text{mW}$$

$$P2 = 79.4\ \text{watts}$$

This corresponds closely to the value of 80 watts arrived at when the graph (figure 13-6) is used.

To find the peak power of the radar, the chart shown in figure 13-7 may be used. The PRF and pulsewidth must be known. They may be obtained by measurement or from descriptive data on the radar.

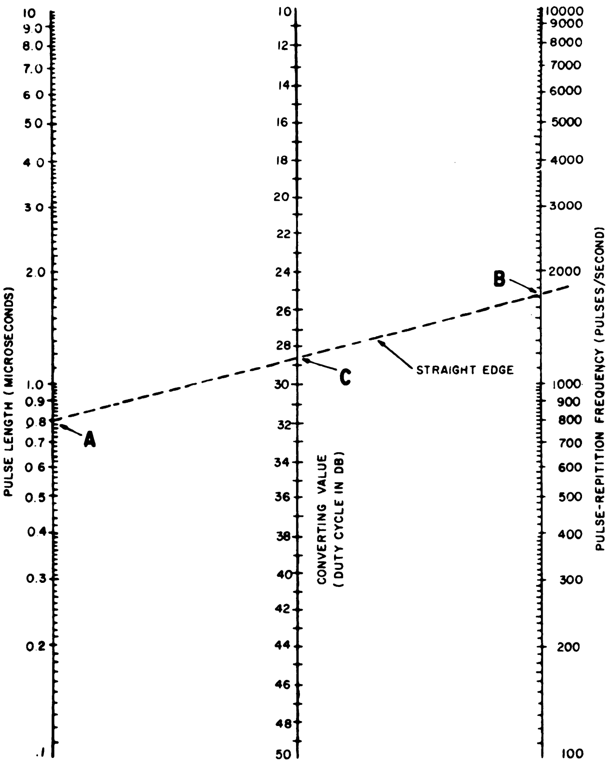

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Figure 13-7.—Average to peak (duty cycle) power conversion chart.

Assume the radar has a pulsewidth of 0.8μ seconds and a PRF of 1706 Hz. Lay a straightedge on the chart, connecting point A (pulse length) and point B (PRF). At point C, read the value of dB (28.6). Add this value to the dBm reading obtained in the average power measurement. Thus, to find peak power, add 28.6 dB to 49 dBm for a total of 77.6 dBm. The graph in figure 13-6 cannot be used in this case since it does not go high enough. However, substituting in the mathematical equation above is appropriate.

$$77.6\ \text{dBm} = 10 \log \frac{P2}{P1}$$

$$10^{7.76} = \frac{P2}{1\ \text{mW}}$$

$$10^{7.76} = P2$$

$$5.75 \times 10\ \text{mW} = P2$$

$$P2 = 57.5\ \text{kW}$$

Two things should now be apparent: Peak power is much greater than average power, and a 28.6-dB gain represents a tremendous increase in power.

RECEIVER

The performance of a radar receiver is determined by several factors, most of which are evolved and established in the design engineering of the equipment. In the following paragraphs, a discussion of those factors concerning maintenance is presented. The most important factors affecting radar receiver performance are receiver sensitivity (including noise-figure determination and minimum discernible signal (MDS) measurement), TR recovery time, receiver recovery time, and receiver bandwidth.

Receiver Sensitivity

Many radar systems contain circuits which serve special functions. Three special circuits commonly found in aviation weapons systems radar are instantaneous automatic gain control

(IAGC), sensitivity time control (STC), and fast-time constant (FTC). These circuits may be found alone or in combination, depending upon the purpose of the radar. When the test methods and procedures about to be described are used, the special functions should be disabled. If an automatic frequency control (AFC) circuit is included in the radar, there may be times when it is operated during receiver tests. A good check on AFC is to complete the tests specified for manual tuning, then switch to AFC. If the AFC circuit operation is normal, signal indications will not change.

Inefficient range performance by a radar system can be caused by troubles in the radar receiver. These troubles result mainly from the great number of adjustments and components associated with the receiver. Loss of receiver sensitivity has the same effect on range as a decrease of transmitter power. For example, a 6-dB loss of receiver sensitivity shortens the effective range of a radar just as much as a 6-dB loss in transmitter power. However, such a drop in transmitter power is very evident and therefore is easy to detect. On the other hand, a loss in receiver sensitivity, which can easily result from a slight misadjustment in the receiver, is very difficult to detect unless accurate measurements are made.

Figure 13-8 shows a comparison of radar system's performance versus maximum range. The system performance loss in dB includes both

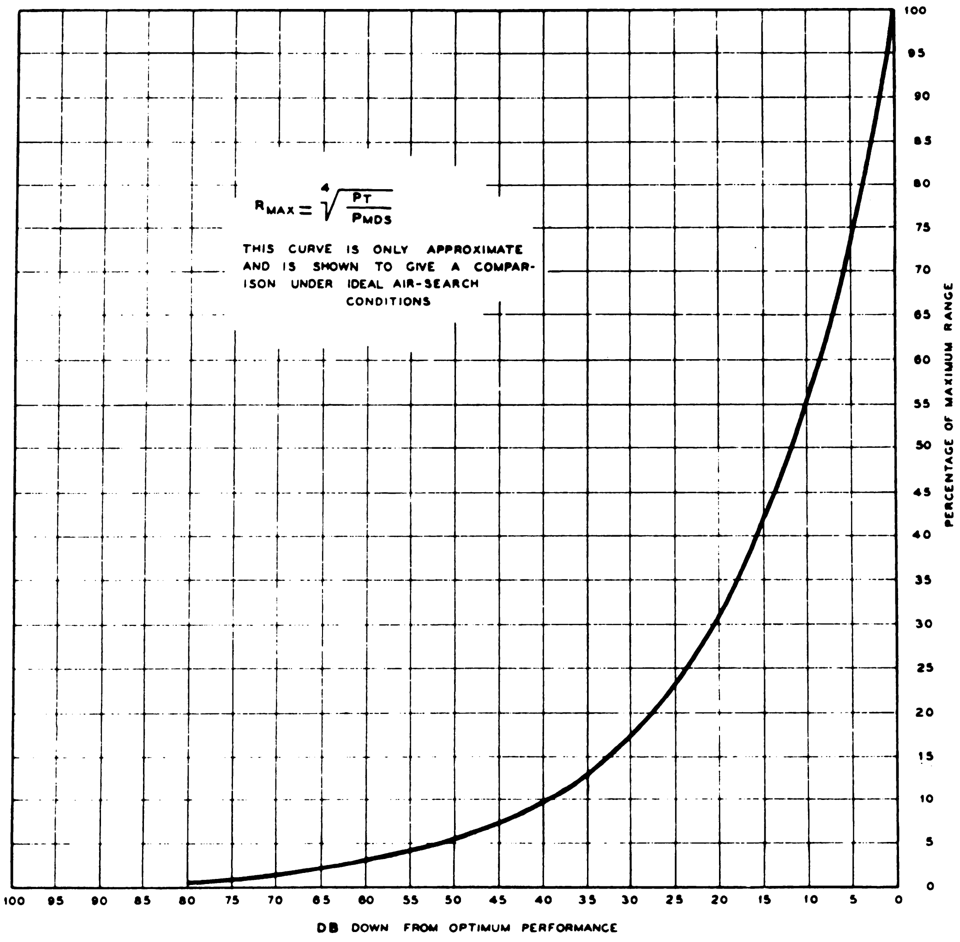

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Figure 13-8.—System performance versus maximum range.

transmitter and receiver losses. It should be noted that with a loss of 5 dB in both receiver and transmitter (total of 10 percent) performance, only 55 percent of the system's maximum range is realized.

The sensitivity of the receiver determines the ability of the radar to pick up weak signals. Greater sensitivity indicates that the receiver can pick up weaker signals. Sensitivity is measured by determining the power level of the MDS. MDS is defined as the weakest signal that produces a visible receiver output. Its value is determined by the receiver output noise level, which tends to obscure weak signals. It follows, therefore, that an MDS measurement is dependent upon the receiver noise level and that measuring either one of these quantities (MDS or noise-figure) will give an indication of receiver sensitivity.

Many weapons control systems have built-in receiver sensitivity test circuits (such as BIT-target generators or ringing oscillators) that give the technician or operator an indication of the sensitivity of the receiver.

The measurement of the MDS is made by measuring the power of a pulse whose level is just sufficient to produce a visible receiver output. If a radar receiver has the MDS level specified for it, the noise figure should be correct. Therefore, measurement of the MDS is a satisfactory substitute for a noise-figure determination. When measuring MDS, the correct pulse length must be used. Also, when readings are taken periodically for comparison purposes, the identical pulse length must be used each time. In most cases, it will be the same as the transmitter pulse length. Maintenance instructions for the radar set will usually specify the pulse length to be used in receiver sensitivity tests.

RECEIVER FREQUENCY MEASUREMENT.—Before any measurements of receiver sensitivity can be made, the receiver must be accurately tuned to the radar transmitter frequency. In order to measure receiver frequency, a test set is connected to the radar set directional coupler.

NOTE: Receiver frequency may be measured using energy from the test antenna; however, to get accurate results, the sensitivity tests that usually follow frequency tests must be made using the directional coupler.

The test set is tuned to the radar transmitter frequency as described in the maintenance instructions manual (MIM) for the test set. Next, the test set dBm control is adjusted to increase attentuation until "grass" appears on the test set CRT. Then, the oscillator frequency control is adjusted until the "grass" disappears from the CRT. These adjustments are repeated alternately until a very small change in the oscillator frequency or any increase in attenuation causes "grass" to appear. The frequency control is then readjusted to cause a maximum dip on the power meter. The reading on the frequency counter now indicates the receiver frequency. If this reading differs from the previously measured transmitter frequency, the radar receiver local oscillator is improperly adjusted, or the transmitter frequency may have drifted.

LOCAL OSCILLATOR ADJUSTMENTS.—To tune the local oscillator, the test set is adjusted according to the MIM, then the transmitter frequency is measured. This adjusts the test set to the transmitter frequency. Next, the frequency control on the test set is adjusted at least one turn away from the transmitter frequency, and the radar local oscillator is tuned for a reduction of "grass" on the test set CRT. At this point, the radar crystal current is adjusted, if necessary, to the level specified in the MIM for the radar set. The attenuation is increased by turning the dBm control until "grass" appears. The local oscillator and attenuation adjustments are repeated until any change in the local oscillator frequency or an increase of attenuation causes "grass" to appear on the CRT. The receiver is now tuned to the transmitter frequency, and it is ready for sensitivity tests.

LOCAL OSCILLATOR REPLACEMENT.—When a klystron local oscillator fails to produce an output of correct frequency or amplitude, it must be replaced. Replacement of plug-in type klystrons is a relatively simple matter. However, caution should be exercised to ensure the klystron or its probe is not damaged. Voltage checks should be made at the filament, cathode, and reflector connections because improper voltages may cause destruction of the klystron.

It takes more work to replace flange-mounted klystrons than plug-in klystrons. Flange-mounted klystrons may be mounted directly to a section of the mixer waveguide, or they may be electrically insulated from the waveguide. If such is the case, all insulating washers, gaskets, and spacers are replaced in a manner that will maintain the electrical isolation of the klystron from the waveguide. A final check with an ohmmeter BEFORE THE POWER IS TURNED ON will establish whether or not the insulation is intact. Now, the klystron is tuned to the correct frequency as previously described.

CAUTION: When the klystron is insulated from the waveguide section, there is normally a negative 250-volt potential applied to the shell. Care must be exercised to prevent physical contact with the klystron while power is applied to the set.

RECEIVER SENSITIVITY TESTS.—There are two basic methods for measuring receiver sensitivity. One is the pulse method in which a pulse of measured amplitude and width is coupled to the radar receiver. This method is rather difficult to use since consistent results require the signal generator be tuned very accurately to the receiver frequency.

The second method employs an FM generator to sweep the signal generator output frequency across the receiver frequency. This method ensures the test signal is within the bandpass of the receiver.

RECEIVER BANDWIDTH TESTS.—Receiver bandwidth is defined as the frequency spread between the half-power points on the receiver response curve. Receiver bandwidth is specified for each radar, but wide variations are tolerated. If either the bandwidth or the shape of the receiver response curve is not within tolerances, a detailed check of circuit components may be necessary. Remember that a considerable change in the value of circuit components is required to alter the response. It is suggested that receiver response be checked after any extensive repair to an IF amplifier.

Figure 13-9 shows a typical response curve of a radar receiver. The half-power points are shown as 3 dB below maximum (midfrequency) response. Since the curve is plotted in terms of voltage, these points are also represented by the 70.7 percent voltage points ($\sqrt{1/2} = .707$) as shown in the figure.

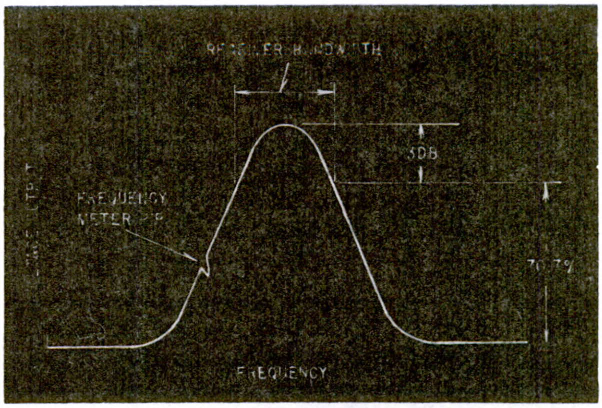

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Figure 13-9.—Receiver response curve.

TR Recovery Time

The time required to permit TR recovery is determined by the time it takes the TR switch to deionize after each transmitter pulse. It is usually defined as the time required for the receiver to return to within 6 dB of normal sensitivity after the end of the transmitter pulse. However, some manufacturers use the time required for the sensitivity to return to within 3 dB of normal or to full sensitivity. TR recovery time is the factor that limits the minimum range of a radar because the radar receiver is unable to receive signals until the TR switch is deionized. In various radar sets, the recovery time may vary from about 3 to 20 microseconds.

The primary function of the TR section is to protect the crystal detectors from the powerful transmitter pulse. Even the best TR switches allow some power to leak through; but, when the switch is functioning properly, leakage power is so small that it does not damage the crystal. It has been found, however, that the useful life of a TR tube is limited because the amount of leakage and the recovery time increase with use.

To ensure efficient performance, some technicians make it a policy to replace the TR tube after a given number of hours of use. A better practice is to measure the TR recovery time at frequent intervals and make a graph or chart, which will immediately disclose any change in performance. Figure 13-10 shows how the recovery time is correlated with power leakage. Note that the end of the useful life of the TR tube is indicated by an increase in recovery time.

RADOMES

Most radar antennas must be protected by a radome. Much time, effort, and money have been expended in the development and production of radomes that will not degrade the performance of the radar. Radomes are precision devices built to close tolerances which must be maintained.

Most radomes the AQ will come in contact with are known as the sandwich-wall radomes. They are constructed of two or more thin skins and are stabilized against buckling by lightweight core material. The skins are normally fiberglass similar to that found in fiberglass boats. Many of the cores are made in the form of a honeycomb. Other cores are fluted or foam.

The main problem the AQ has is preventing physical damage to the radome during the performance of the job. The outer skin of the radome is sometimes sprayed with a rubber-type substance to keep any contaminating fluids from causing damage to the walls. This coating must be protected from physical harm. The walls of the radome are very thin, but they are of sufficient strength to withstand wind forces expected in flight. They are not built to withstand stress which a sharp instrument may apply. Therefore, when handling a radome during maintenance, the technician must be especially careful not to slam it against any hard, sharp edge, such as the edge of another aircraft control surface or against the corner of an auxiliary power unit.

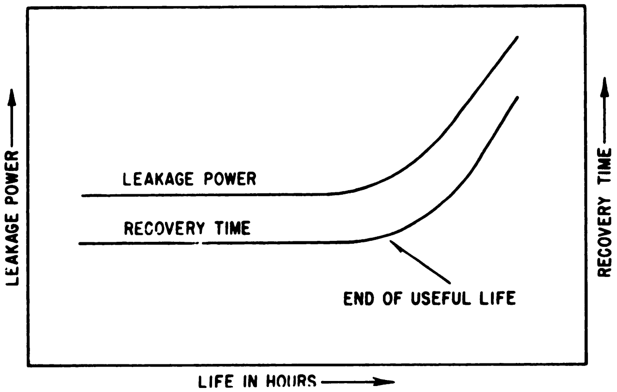

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Figure 13-10.—Graphic comparison of TR recovery time and leakage power.

When the radome is of the hinged type, it must be properly lubricated. This is a major maintenance consideration. The skin surfaces must be kept clean and free of oil or grease. If physical damage does occur, repair of the damage is dependent upon the extent of the damage and the area in which the damage occurs. Normally, the AQ is not required to make physical repairs. These are usually done by squadron AMs in case of minor damage or, when there is extensive damage, by a specialist at an intermediate or overhaul activity.

BORESIGHTING

Boresighting is a necessary maintenance function to maintain the weapon system accuracy. The accurate and effective delivery of aircraft firepower to a selected target is as dependent on accurate boresighting as on proper operation of all other related equipment. Unless accuracy is maintained, the expense of the equipment involved is not justified.

The purpose of boresighting is to establish a specific relationship between the aircraft armament datum line, antenna RF and optical axes, optical sight unit, and launchers. If guns are aboard (other than the Mk 4 gun pod), they are also included in the boresight procedure. Normally, any adjustment required by the guns, launchers, and noncomputing sights is performed by the AO. The AQ is responsible for boresighting the radar and computing gun sights.

The equipment necessary to carry out the boresight procedure varies from one installation to another. However, a boresight board or screen and a telescopic boresight kit with associated fixtures are normally required in all situations. In any case, the appropriate MIM must be consulted for specifications pertaining to these items as well as to test sets and other equipment needed.

The primary boresight reference to which the entire aircraft is aligned is the zero-zero radar axis. This axis is the line in space along which the radar antenna will look when tracking a target with zero azimuth and zero elevation gimbal angles. The antenna is fitted with a boresight fixture to accept a telescopic sight for optical boresighting. This fixture can be used as a secondary reference after it has been aligned with the radar axis.

Satisfactory boresighting can be accomplished without radiating, provided the optical axis is in agreement with the RF axis of the radar antenna. This alignment will remain valid as long as no portion of the antenna structure becomes mechanically damaged. If there is reason to believe that the antenna has been mishandled, or if the feed horn or reflector appears to be deformed, a complete boresight should be conducted.

There are three methods of boresighting. The first is the full boresight. It provides for a complete RF and optical boresight, which determines the state of alignment of the radar axis and optical axis. The MIM should be consulted for the step-by-step procedure.

The second method is the radar silence boresight. It is the same as the first method except the telescope fixture only is used as the reference. This procedure can be used whenever it is impossible to radiate, or sufficient time does not exist for the full procedure.

The third method, called fast boresight, is for use only with the director portion of the aircraft armament. It can only be used when the aircraft has been boresighted previously, using the full procedure with a given antenna. This method can then be used to establish the electrical boresight of the director.

MINI-SACE

The purpose of the miniaturized semiautomatic checkout equipment (Mini-SACE) is to check the performance of individual electronic boxes of various electronic systems located in the A-6 aircraft and to isolate malfunctions to a replaceable module or circuit. A typical Mini-SACE test console is shown in figure 13-11.

The programmer-comparator OQ-35A/ASM-347(V) is the heart of the Mini-SACE system. The programmer-comparator controls the operation of the Mini-SACE system by measuring, evaluating, and sequencing the tapes used for GO/NO-GO testing and fault isolation.

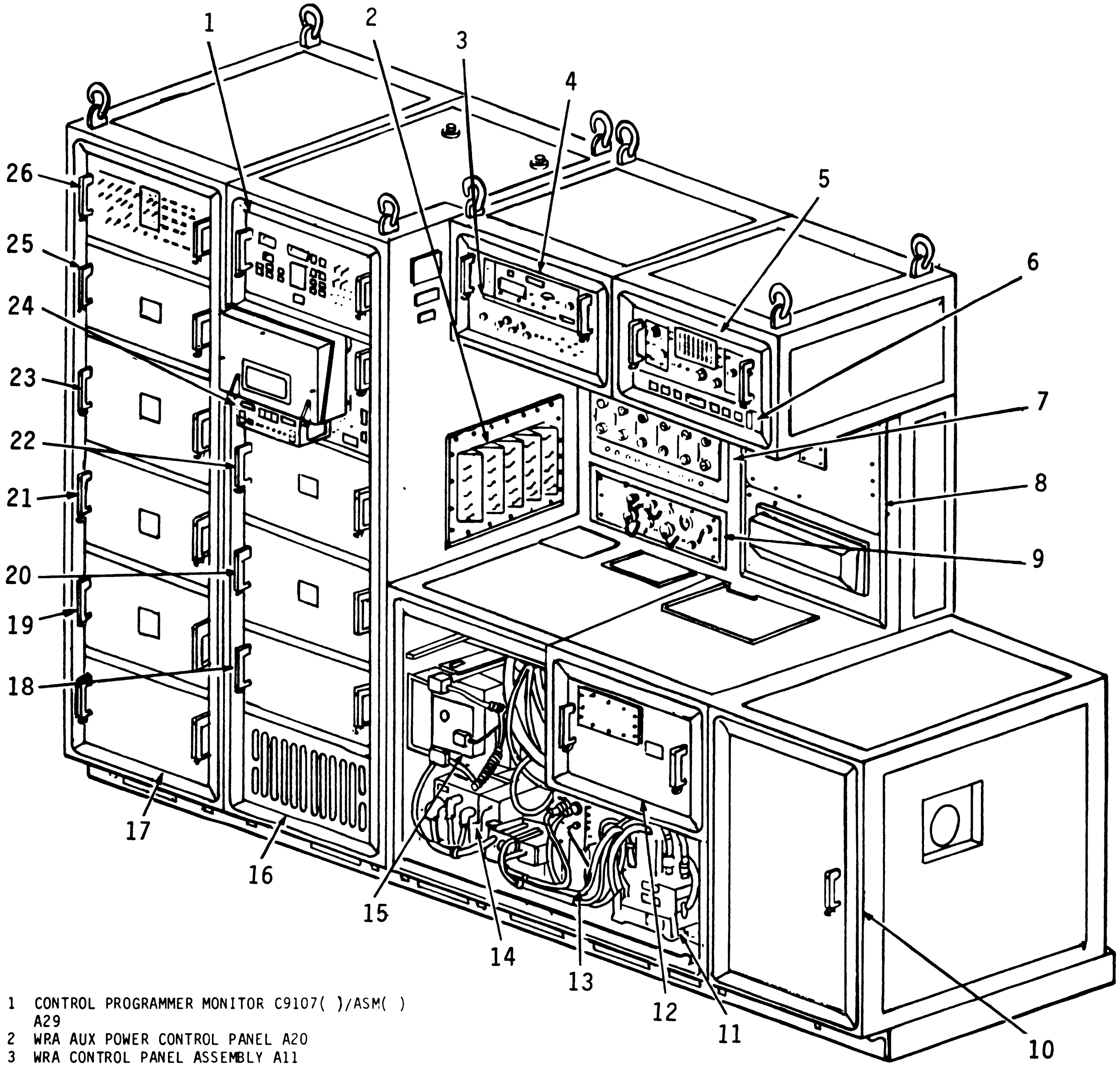
The programmer-comparator provides preprogrammed, tape-generated stimuli to the test bench. The stimuli is converted by the test bench to digital or analog signals that simulate the normal inputs of the weapon replaceable assembly (WRA) being checked. Responses to the stimuli are fed back to the programmer-comparator. Here they are compared against high and low parameters. An indication of the results (GO, HI, LO, (no-go) or POL (wrong polarity)) is displayed on the control panel. If the results of a test are other than GO; i.e., HI, LO, or POL, the tape automatically stops and must be restarted manually. After the faulty module, or groups of modules is/are discovered, the faulty component of the module is isolated by the use of an avionics test bench and by using manual troubleshooting techniques.

VAST

The Versatile Avionics Ship Test (VAST) system (AN/USM-247(V)) is currently installed aboard naval aircraft carriers and shore installations. VAST is designed to deal with the continually changing field of avionics testing. VAST has significantly reduced the space required by equivalent special- and manual-support equipment.

In its basic form, a VAST station is assembled from an inventory of functional building blocks. These building blocks furnish all the necessary stimuli and have the measurement capability to check current naval avionics equipment. As new equipment is developed and introduced, the test station configuration may be modified. As it becomes necessary, new building blocks are added to furnish new parameters for greater precision to existing capabilities.

A typical VAST test station consists of a computer subsystem, a data transfer unit, and a stimulus and measurement section containing functional building blocks configured to meet the



1 CONTROL PROGRAMMER MONITOR C9107( )/ASM( ) A29
2 WRA AUX POWER CONTROL PANEL A20
3 WRA CONTROL PANEL ASSEMBLY A11
4 DIGITAL MULTIMETER A10
5 OSCILLOSCOPE A14
6 REMOTE READOUT PANEL A15
7 WRA DISTRIBUTION PANEL A12
8 ELECTRICAL DUMMY LOAD DA-641( )/APM-375( )/A16
9 WRA SERVICE PANEL A13
10 COOLING SYSTEM
  BLOWER B1
  COMPRESSOR A27
  PRESSURE SWITCH A28
11 RADAR MODULATOR MD402(*)/APQ-92(*) A24
12 PROGRAMMABLE MICROWAVE DRAWER A3
13 POWER SUPPLY PP281(*)/APQ-92(*) A23
14 RADAR TRANSMITTER T 1192(*)/APQ-148(*) A22
15 ELECTRONIC CONTROL AMPLIFIER AM 2912(*)/APQ-92(*) A21
16 AIR FILITER ASSEMBLY
17 STORAGE DRAWER
18 STORAGE DRAWER
19 POWER SUPPLY PP 6933( )/APM-375( ) A5
20 CONVERTER SIMULATOR (NO. 2) CV-3119( )/APM-375( ) A9
21 CONVERTER SIMULATOR (NO. 3) CV-3066( )/APM-375 A4
22 CONVERTER SIMULATOR (NO. 1) CV-3118( )/APM-375( ) A8
23 SIGNAL SELECTOR SA 1878/ASM A19
24 PROGRAMMER COMPARATOR OQ-35A/ASM-347(V) A30
25 POWER SUPPLY PP 6880/ASM A2
26 POWER CONTROL INDICATOR C 9350( )/APM-375( ) A1

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Figure 13-11.—Mini-SACE Search Radar Test Control AN/APM-375B, -375C, -375D.

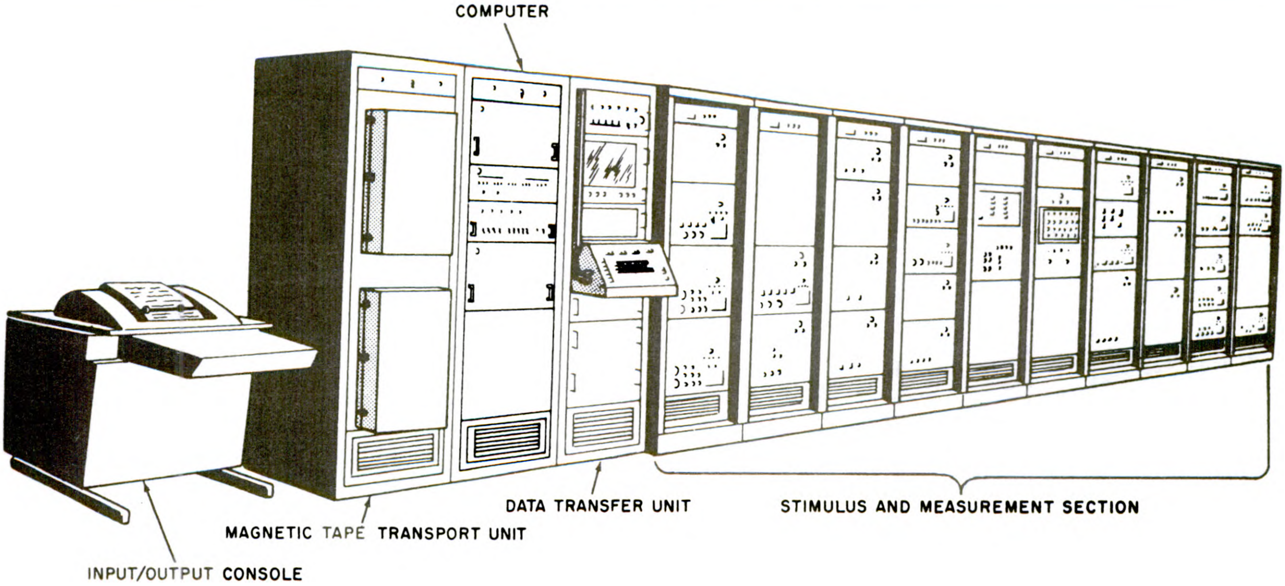

COMPUTER
DATA TRANSFER UNIT
STIMULUS AND MEASUREMENT SECTION
MAGNETIC TAPE TRANSPORT UNIT
INPUT/OUTPUT CONSOLE

Figure 13-12.—Typical carrier-based VAST test station. 223.13

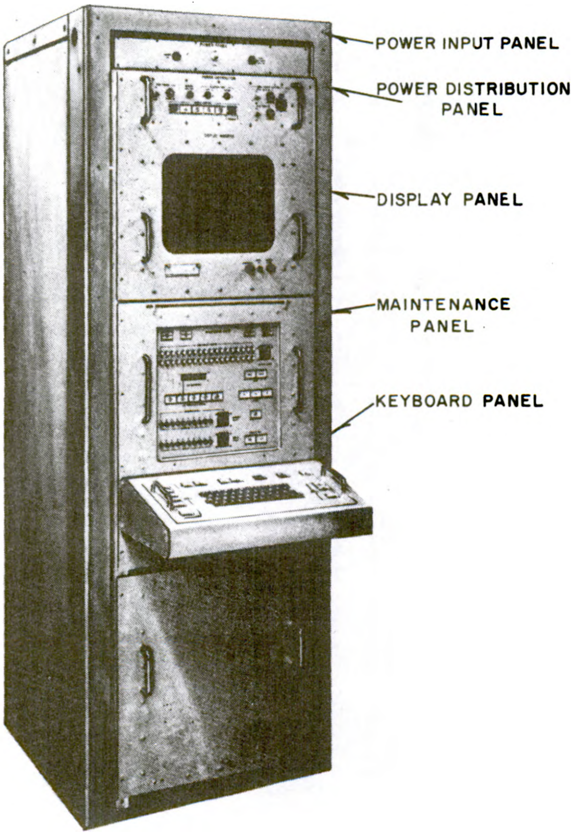
intended test application. Figure 13-12 shows a typical carrier-based VAST test station.

The test station is controlled by a computer subsystem which executes test programs to assure accurate and satisfactory testing. The computer subsystem includes a general purpose digital computer which executes test routines and also provides diagnostic and computational capabilities. It also processes data and furnishes a permanent record of test results. Two magnetic tape transports provide rapid access to avionics test programs and immediate availability of VAST self-check programs.

The data transfer unit (DTU) (figure 13-13) serves as the operator-machine interface. It synchronizes instructions and data flow between the computer and the functional building blocks. Also, it contains the display and control panels.

The DTU control panel permits the operator to communicate with the computer and with the stimulus and measurement section of VAST by means of a keyboard and mode select key. The test station may be operated in three modes—manual, semiautomatic, or fully automatic.

The DTU contains a maintenance panel which monitors station auto-check results and indicates building-block faults. Transmission of instructions from the control computer is on a request/acknowledge basis. Essentially, the response rate is controlled by the stimulus and



223.14
Figure 13-13.—Typical data transfer unit.

measurement systems. This permits instructions to be transmitted at an asynchronous rate corresponding to the maximum frequency at which a given building block or avionics unit can respond. Therefore, there is no requirement for immediate program storage in the DTU.

Typical Station

A VAST station may have as many as 14 racks of stimulus and measurement building blocks (figure 13-14). Large station configurations may contain as many as 17 core building blocks. Core building blocks are designated as a result of high-use factors, or because they are needed for self-test requirements. Building blocks not in the core category are usually selected in accordance with specific test requirements relevant to shop operations or avionics equipment on board ship. In general, the location of such peripheral building blocks is flexible. In order to maintain standardization between VAST stations, the effects of building block interconnection cable losses and switches have to remain within predictable limits. It is the purpose of the core concept to assure this.

VAST was designed with ease of maintenance as a primary objective. In addition to the modularized design of VAST building blocks, there are three levels of fault detection which ensure rapid confidence tests and easy fault location. The three levels of detection are auto-check, self-check, and self-test.

Fault detection may be initially made through auto-check. The auto-check is inherent in the logic and control design of the test station and includes verification of instructions and fault monitoring. Auto-check is carried out on a continuous basis during station operation and, when a fault occurs, testing is interrupted.

The second level of VAST fault detection is self-check. Self- check is a programmed sequence which is initiated by the VAST operator through the DTU keyboard. Self-check may be either internal or system level. Internal self-check measures the ability of a building block to perform against its own internal standards. System self-check requires the use of two or more building blocks in a test configuration selected to isolate faults within the test setup.

The self-check philosophy used to verify the operation of VAST is based upon confirmation of key system elements first. Then, these elements are employed to check the remaining building blocks. Fundamental core building blocks are checked by means of internal standards. Once

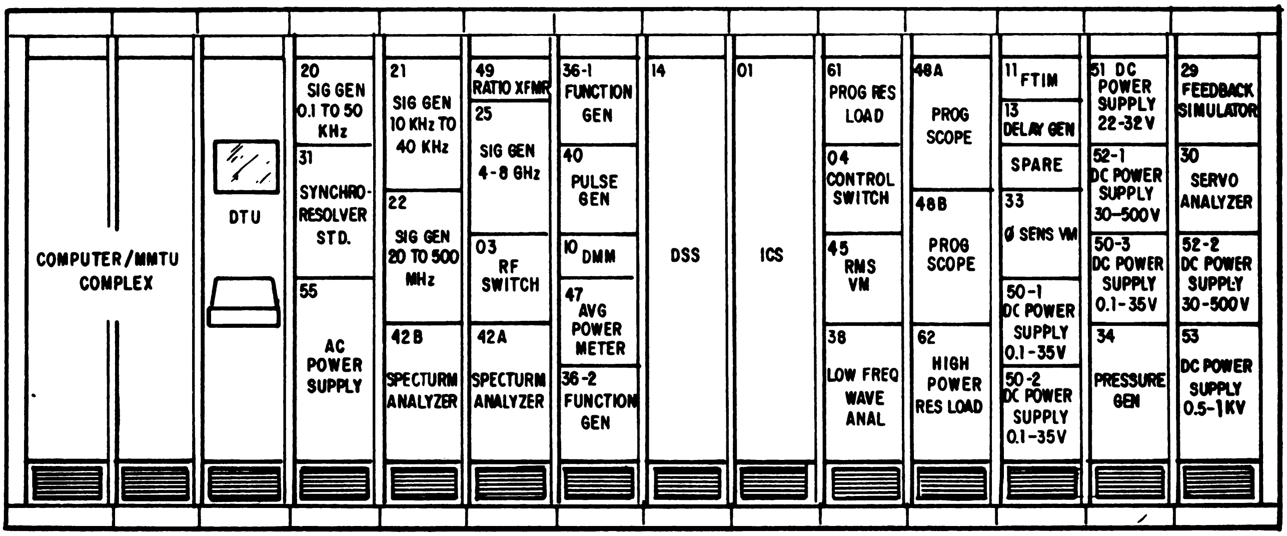


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Figure 13-14.—VAST test station with building blocks.

satisfactory performance has been assured, their capabilities are used to check the remaining building blocks. The checkout of noncore building blocks is then accomplished by using any combination(s) of core measurement and stimulus building blocks.

The final level of VAST fault detection is self-test. This is a series of test programs used to locate faults within a building block. If a building block has been found to contain a malfunction as a result of a self-check routine, then self-test programs are conducted by removing the faulty building block from the VAST rack and connecting it to the test station in the same manner as if it were a unit under test.

To assure optimum support by VAST, it is essential that avionics equipment be designed to be adaptable to automatic testing. Moreover, test programs must be prepared which are compatible with VAST performance characteristics.

Interconnecting Device

Included in the program design is the all-important interconnecting device design. In its simplest form, the interconnecting device consists of an adapter cable, which connects the unit under test (UUT) to the VAST interface. In some cases, however, it is necessary to introduce, as part of the electrical interface in the interconnecting device, passive and active circuits to change impedance levels or to amplify low signals. Ordinarily, this is not required if avionics equipment has been designed within the requirements of VAST. Very often, passive circuit functions are obtained through the use of standard plug-in modules.

The last element of the test program is the instruction booklet or microfilm strip. These detail all the steps to follow in testing any given unit from initial procedures, such as hookup and clearing operations, right down to the final stages of disconnect and UUT closeout.

Operation of a VAST Station

In the typical VAST test procedure, ease in operation of the actual testing becomes apparent. The initial setup of the weapon replaceable assembly, including removal of dust covers, cooling provisions, and connections to interface device, may be made off-station in order to minimize disruptions of station operators. Final connections between the VAST stations interface panel and the UUT are made in a few moments directly at the station.

The operator begins testing by selecting the code which initiates the test program. Prior to applying power or stimulus to the UUT, continuity tests are run to ensure that the proper test program has been selected and that no condition exists which will damage the VAST station or the unit under test once active tests are started. If everything checks out, the testing proceeds automatically. The operator only has to respond to instructions that appear on the CRT display. The program will not stop until a fault is encountered or a program halt is reached.

The purpose of programmed halts is to allow manual intervention during the course of testing to make adjustments and observations. When the identification of faults and the operator's instructions are required (such as interpreting a complex waveform), the operator may be referred to the test program instructions. Upon completion of the test program, the CRT display indicates close-out procedures.

A VAST test station is completely autonomous and normally operated under computer control in a fault automatic mode, stopping only as previously mentioned. Of course, the operator can select any one of these semiautomatic modes or a manual mode.

The semiautomatic modes include a one-group, a one-test, and a one-step mode. These auxiliary modes permit detailed observation of various test sequences, and they are useful in performing work-around procedures in reconciling differences in equipment and program mode status, and in the verification of repairs.

In the manual mode, the test station is completely off-line with respect to the computer. Instructions are introduced by the operator through the keyboard on a one-word-at-a-time basis (figure 13-15). Although the manual mode is never used for avionics testing, it is useful for debugging new programs, integrating new building blocks into the station, and performing self-check operations on some of the building blocks.

REFLECTOMETRY TEST SETS

Multipurpose test equipment is discussed in Chapter 9 of *Avionics Technician (AQ/AX/AT) 3 & 2*, Part I. Unlike that equipment, reflectometry test sets are designed primarily to aid organizational maintenance technicians in verifying and troubleshooting aircraft wiring, transmission lines, waveguides, and antenna systems. They can, however, be used by intermediate maintenance technicians to verify cable connectors, to determine test cable impedances, and to troubleshoot test equipment.

The Navy presently uses two types of reflectometry test sets. They are time-domain reflectometer (TDR) and frequency-domain reflectometer (FDR) testers. A discussion of the theory of TDR testing and an introduction to one of the common testers in use is presented in this section. There are many models of reflectometers testers, but their basic functions are the same.

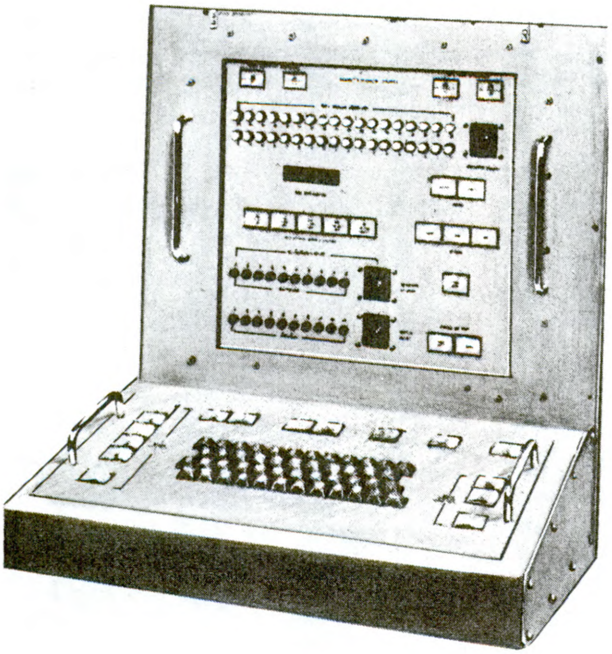

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Figure 13-15.—Typical VAST control panel.

TIME-DOMAIN REFLECTOMETRY (TDR) TEST SETS

Time-domain reflectometry (TDR) test sets are used mainly to check/troubleshoot aircraft wiring, transmission lines, and antenna systems for shorts, opens, crimps, or bad couplings. The TDR accomplishes these tasks by monitoring reflected waveforms. TDRs operate on the same principle as radar. That is, they send pulses of energy into a system to see what, if anything, is reflected. As with standing waves on an antenna line, if nothing is reflected, the impedance of the transmission line is uniform and properly terminated. But if such problems as crimps, opens, or bad couplings are present, a discontinuity will exist and pulses in phase, or out of phase will return to the TDR test set and be displayed on its CRT as positive, negative, or simply fast-rising voltages, signifying known causes usually at fault. Impedances greater than 50 ohms are seen by the TDR as in phase, while those less than 50 ohms are seen as out of phase. These are respectively classified (traditionally) as inductive and capacitive faults, readily explained by the basic equation: $z_o = \sqrt{L/C}$. This, of course, specifies the equalities of inductance (L), capacitance (C), and impedance (Z).

TDR BASICS

The TDR analysis begins with the insertion of a step or pulse of energy (referred to as the "incident signal") into a system or cable and the subsequent observation, at the point of insertion, of the energy reflected by the system or cable under test. Figure 13-16 shows the typical TDR analysis. The output of the pulse generator is a step-signal with a rise time of approximately 110 picoseconds. This signal (incident signal) goes through a sampling tee to the CRT of the oscilloscope and to the system under test via 50Ω termination connector. The equivalent bandwidth of the CRT deflection circuits provides a system rise time of approximately 140 picoseconds. This allows the TDR to give resolution (detect faults) as

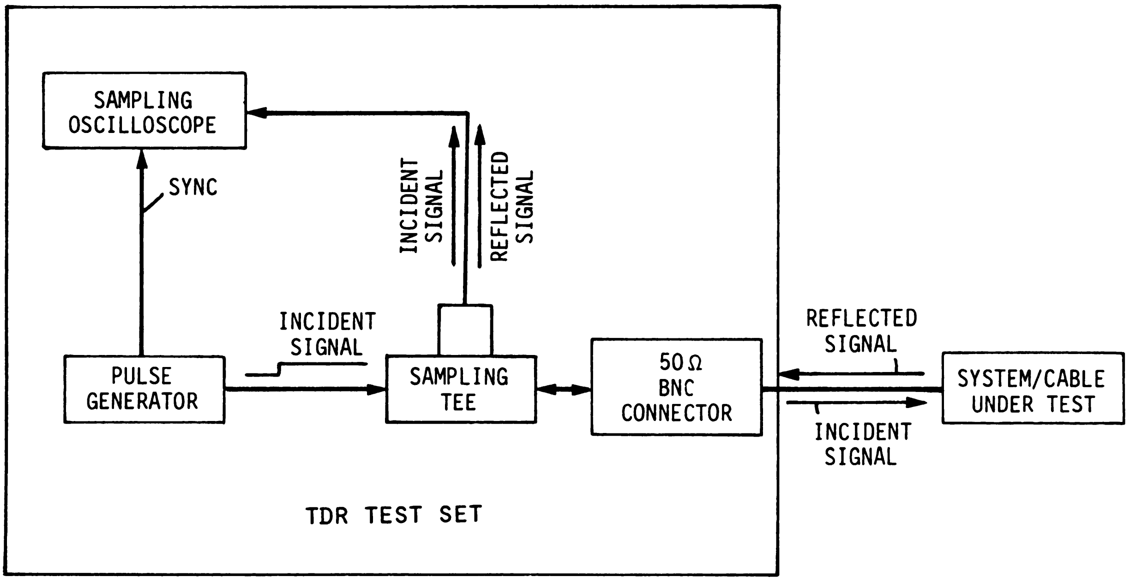

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Figure 13-16.—Typical TDR analysis.

close as 1/2 inch apart. The reflected signal from the system under test reenters the TDR test set and returns via the sampling tee to the oscilloscope CRT along with the incident signal. By comparing the magnitude, duration, and shape of the reflected signal, the nature of the impedance variation in the system under test can be determined.

Resistive Loads

If a pure resistive load is placed on the output of the TDR, and a step signal is applied, a signal whose amplitude is a function of the resistance (see figure 13-17) is observed on the CRT. If the line is terminated in its characteristic impedance

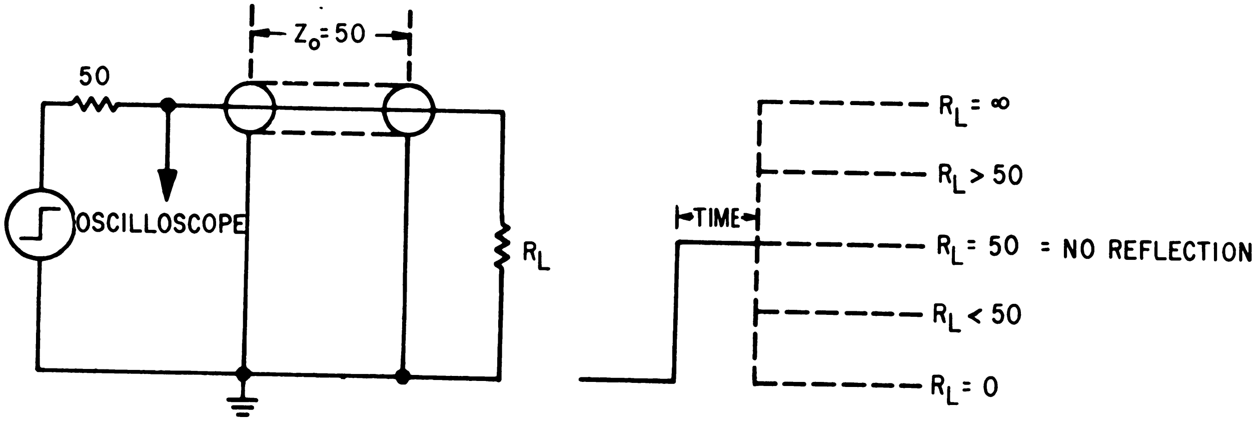

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Figure 13-17.—Step signal-height variations resulting from different resistive loads.

(Z_o) as shown in figure 13-17, there will be no reflected signal, and the signal observed on the CRT will remain flat. But if the impedance (R_L) at the termination is greater or less than Z_o, then reflections (standing-wave ratio [swr]) will exist. The amplitude of the reflected signal is proportional to the value of R_L. If R_L is greater than Z_o (50Ω), the reflected signal will be in phase with the incident signal; and when applied to the CRT, will add to the incident signal. If R_L is less than Z_o, the reflected signal will be out of phase with the incident signal; and when applied to the CRT, will subtract from the incident signal. The dotted lines in figure 13-17 represent various composite signals (incident ± reflected) that would be observed for various values of R_L. The time from the start of the incident (step) signal to the step created by the reflected signal, represents twice the distance to the discontinuity. That is, the time it took the incident step to reach the discontinuity and return. Most TDRs are calibrated to read this time in feet or inches to the discontinuity.

It is good practice to separate the system under test from the TDR test set by eight inches of 50-ohm cable. This moves the reflections away from the leading edge of the step (start of incident signal), to prevent overshoot and ringing from being superimposed on the observed CRT signal.

Reactive Loads

The waveform of reactive loads (figure 13-18) depends upon the time constant formed by the load and the 50-ohm source. The series RL network in (A) of figure 13-18 appears as an open the instant the step voltage reaches it, because the inductor L offers maximum impedance to the change in current caused by the step voltage. Therefore, the reflected signal is in phase with the step voltage and is additive. This explains the sharp rise in voltage. However, as soon as the inductor saturates, the only opposition to current is resistor R; and since L saturates at a nonlinear rate, the voltage drops at a nonlinear rate from the peak of the spike to the same level as the flat portion of the step voltage. At this time the only load seen by the line is the 50-ohm resistor, which is equal to the characteristic impedance of the line, and the reflections cease until the next step appears at the termination, and the cycle repeats itself.

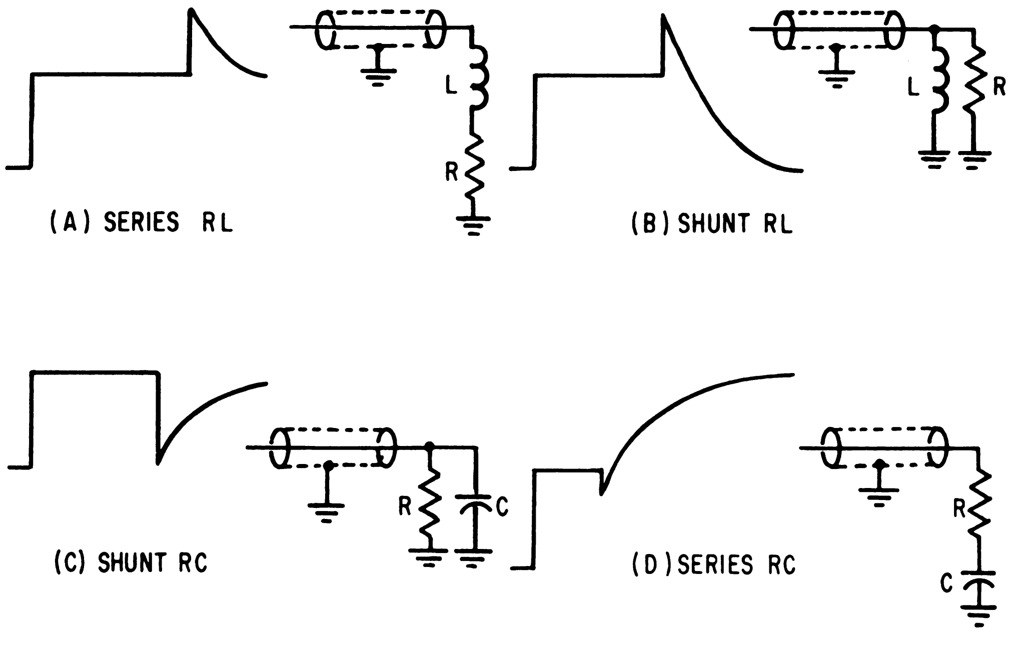

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Figure 13-18.—TDR reactive lead characteristics (time constant = 1).

You can understand the waveshape in figure 13-18(B) by remembering that L appears as an open to the fast rising step voltage the instant it is felt at the termination. However, as the inductor saturates, it offers less and less opposition to current until it is completely saturated (0 ohm). Since the inductor is parallel to R, the termination is a short, and the reflected wave is 180° out of phase with the incident wave. Since L saturates at a nonlinear rate, the voltage declines at a nonlinear rate. A similar analysis can be made of the transmission lines with the RC terminations shown in (C) and (D) of figure 13-18.

The analysis just made of the different types of discontinuities explains the usefulness of TDR. Not only can a discontinuity be determined, but through proper analysis you can determine whether it is resistive, inductive, or capacitive, and whether it is in series or parallel with the load.

TDR IN PRACTICE

TDR discontinuities are clearly separated in time on the CRT. It is easy to see the mismatch caused by a connector even if a bad discontinuity is present elsewhere in the system. By using the analysis explained previously, you can establish which connector is troublesome and in what way. Once you have determined that a discontinuity appears in a waveform, it is simple to locate it in the system. A timesaving way of doing this is to calibrate the system so that one centimeter on the horizontal axis is the equivalent of a certain number of feet for the transmission system under test. The limiting factor is the system rise time, and any closely spaced discontinuities will appear as a single discontinuity.

The finite rise time also limits the size of the distinguishable reactive impedance response. For example, a small shunt capacity in a 50-ohm system will cause the waveform to depart from the ideal response (figure 13-19).

The maximum observable line length is a function of the repetition rate chosen. This rate determines the duration of the pulse after its rise. For example, a 200-kHz repetition rate permits the use of TDR devices with up to 1,000 feet of air dielectric cable or 670 feet of polyethylene dielectric coaxial cable. The speed at which a wave travels through a transmission system is determined by the system's velocity constant; thus a wave travels faster through air than through polyethylene. This explains the difference in maximum lengths of coaxial cable that can be checked using a particular repetition rate on the TDR—the longer the cable, the lower the repetition rate must be.

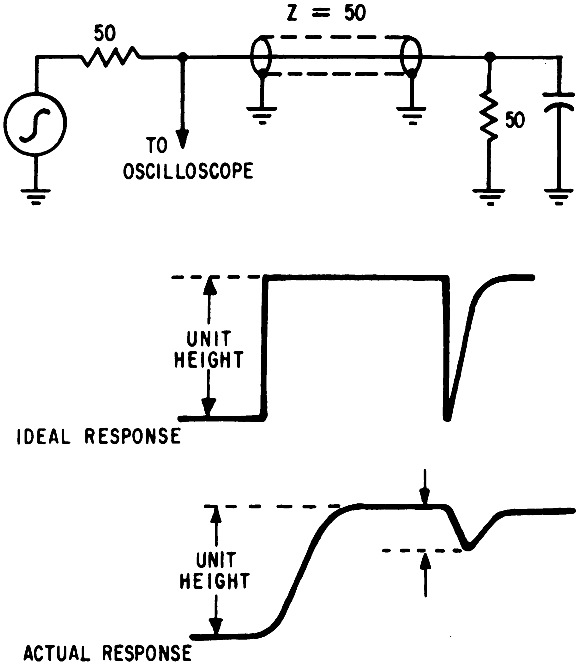

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Figure 13-19.—Small shunt capacity in system degrades ideal response.

RANGE AND RESOLUTION

Assuming that the total impedance (Z_0) equals 50 ohms, a resistance between 0.025 ohms and 100 kilohms may be measured. Because the height of the reflection is directly proportional to the resistance encountered, the resistance may be determined by the use of a precalculated transparent overlay.

One common use of TDR is in analyzing a coaxial cable. The amount of impedance variation that can be detected in a long section of cable is a function of the flatness of the top of the incident step. If this step is flat within ± 1/2 percent, impedance variation of 1/2 ohm along the cable can be detected, corresponding to a one percent check on cable impedance. Thus, irregularities in cable makeup resulting from variations in the braiding process or tightness of the insulating jacket show up clearly.

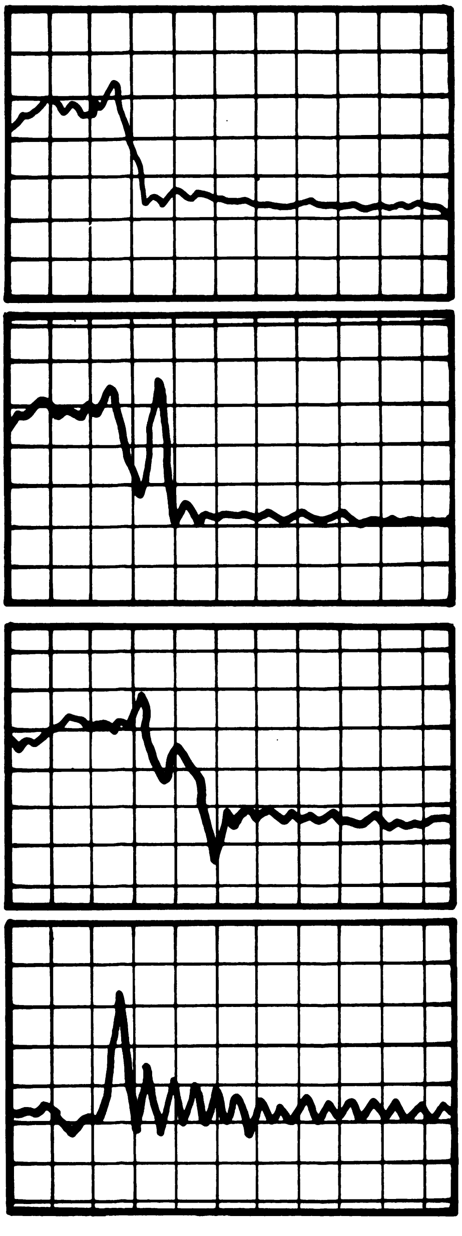

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Figure 13-20.—Waveforms resulting from the use of different loads. Horizontal scale to 0.4 μsec/cm; vertical scale 0.5 percent/cm.

ANALYZING TERMINATIONS

Departure from 50 ohms in a termination or cable connector can cause large reflections in a pulse system or a large voltage standing-wave ratio (VSWR) in a system that carries primarily sinusoidal signals. Because of human errors in the assembly process, even the best connectors unfortunately cause reflections or a varying VSWR. Expensive connectors, therefore, do not ensure freedom from unwanted reflections, but TDR helps locate unacceptable connectors by rapidly showing where the mismatches are, how bad they are, if they are resistive, capacitive, or inductive, and whether series or shunt. Figure 13-20 shows a step being propagated from a section of RG9A/U into a load. The connector on the load and the cable are the General Radio Type 874. Four different cases are shown with varying loads, thus illustrating how the connection and the load can be analyzed by use of the TDR. With different connectors and loads, the small mismatches (discontinuities) take on different impedance characteristics and the reflected signals change. This change is also reflected in the waveshape viewed on the oscilloscope. A comparison between these signals and those of a normal system can be made by using an overlay showing the pattern of a normal system.

Cable Impedance

The most convenient method of reflectometer use in making precise measurements of cable impedance is to connect a section of air dielectric

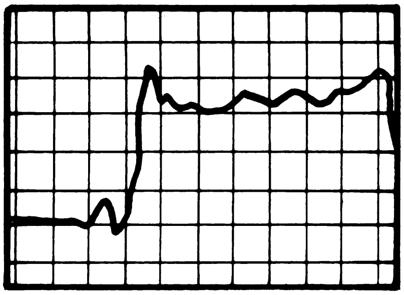

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Figure 13-21.—Oscillograph of step from air dielectric line into test cable.

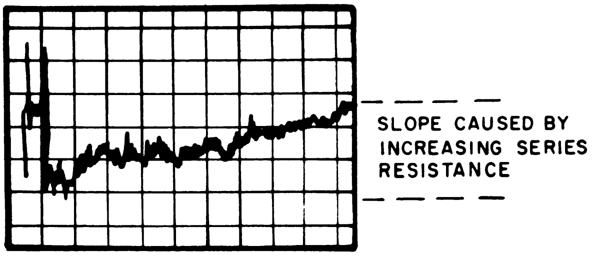

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Figure 13-22.—Trace of cable shows construction irregularities and increasing series resistance.

line (with precisely determined impedance) between the test cable and the TDR unit. The step height through the air dielectric line section sets the 50-ohm level. Variations from this level in the test cable are noted, and the impedance of the cable is calculated (figure 13-21). In this test, the impedance level of the test line is

$$Z_o = 50\frac{1+\rho}{1-\rho}$$

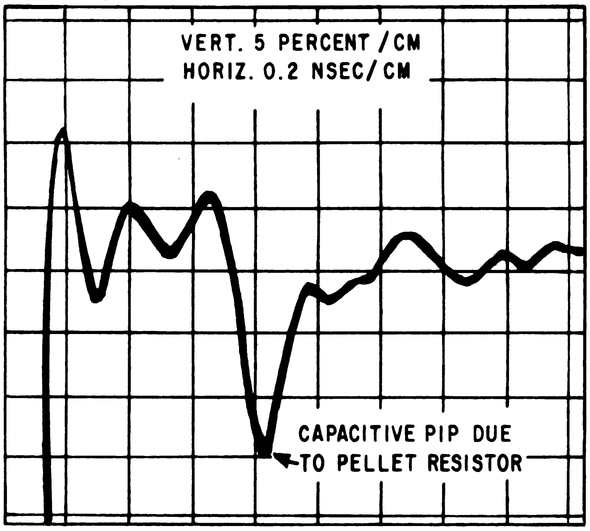
where ρ is the reflection coefficient of the reflected mismatch. The change in amplitude shows ρ to be + 0.03, so:

$$Z_o = 50\frac{1.03}{0.97} = 53 \text{ ohms}$$

The impedance of a long section of coaxial cable would be exactly Z_o if there were no line losses. However, most cables have a small series loss and a negligible shunt loss. This series resistance adds to Z_o, causing the impedance level, as observed at one end of a cable, to increase as longer sections of cable are added. The slope on the step height that results from the increasing impedance is evident in figure 13-22.

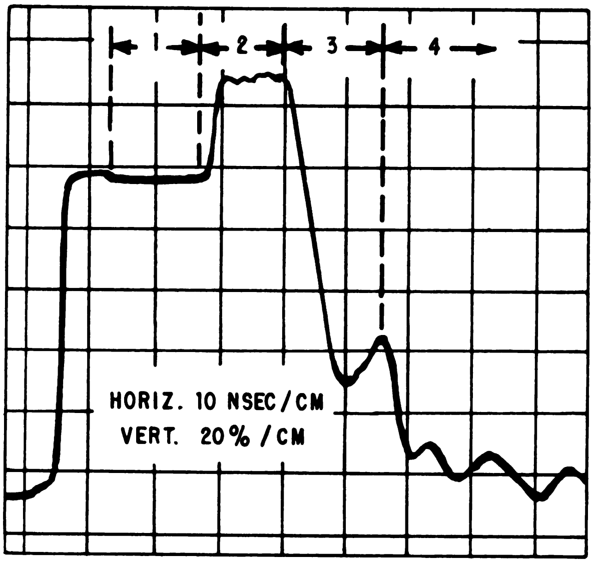
Other applications in which the TDR method of analysis can be used effectively are component characteristic analysis and antenna analysis. The components can be placed in an appropriate jig and the TDR method used to determine their shunt capacity and series inductance (figure 13-23).

Investigation of antennas will reveal that the TDR pattern is not simple, but instead presents a complex reactive profile (figure 13-24). Once you



229.416

Figure 13-23.—Resistor checked for shunt capacity with special jig.



1. 50-ohm feedline. 3. Short at end of antenna.
2. 75-ohm antenna. 4. Rereflections.

229.417

Figure 13-24.—Scope trace of antenna reactive profile.

determine the proper profile for a particular antenna, you can detect any improper construction details and ascertain the proper corrective action.

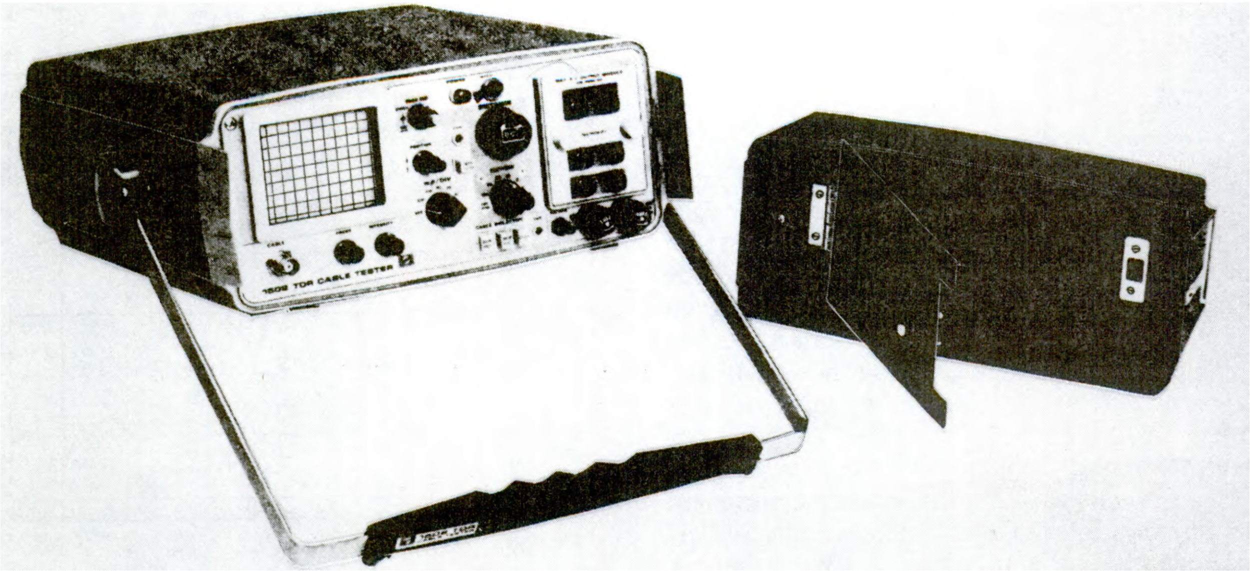
TEKTRONIX 1502 TDR TESTER

The Tektronix 1502 (see figure 13-25) is a portable, battery-powered TDR which uses radar principles to test cables and provides a visual CRT display of cable faults. It also has an output to drive a chart recorder if a permanent record of a test is required. The battery pack provides approximately five hours of operation of the equipment and is rechargeable. The equipment contains charging circuits for the battery pack. A three-pronged power cord is provided which, when plugged into a 115-volt ac source, will energize these charging circuits, and also allow operation of the tester while the battery is charging. It takes 14 to 16 hours to fully charge a discharged battery pack.

The output pulse of the 1502 is a step-signal with an amplitude of approximately 225 mV. The rise time of the pulse generator and the equivalent bandwidth of the deflection circuits provide a system reflected rise time of 140 picoseconds. The displayed rise time of the incident edge of the step signal is 110 picoseconds. Vertical deflection of the CRT beam is proportional to the amplitude of the reflected signal plus the incident step. The vertical scale on the face of the CRT (see figure 13-26) is calibrated in units of rho (ρ) of the transmitted pulse amplitude. The technical definition of rho (ρ) is resistivity, volume charge density, coordinates. On the 1502 TDR tester, rho is dependent on the characteristic impedance (Z_o) of the cable under test and the load (or the impedance of the discontinuity), R_L, on the cable. It can therefore be expressed as

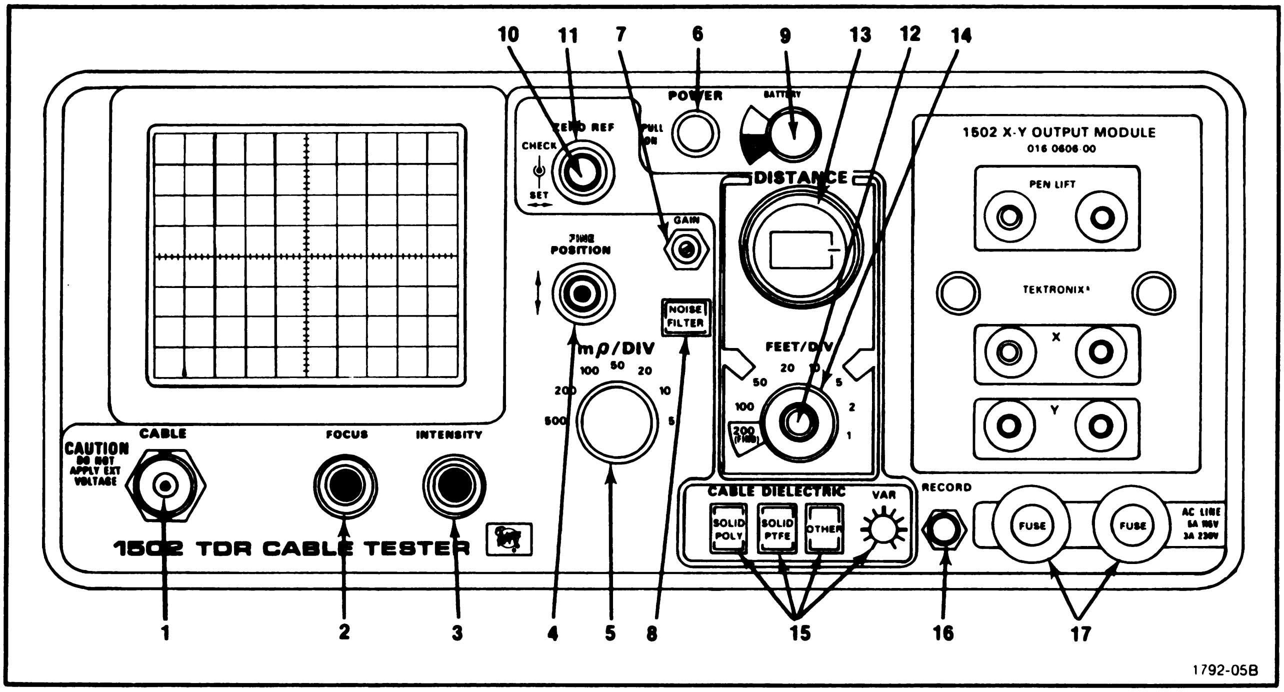
$$\rho = \frac{R_L - Z_o}{R_L + Z_o}$$

This relationship was used to develop a ρ versus impedance chart (figure



222.564

Figure 13-25.—Time-domain reflectometer.



1. CABLE	BNC Connector—delivers pulse to the test cable and receives the reflected return pulse.
2. FOCUS	Adusts the focus of the crt electron beam.
3. INTENSITY	Controls the brightness of crt display.
4. POSITION/ FINE	Vertical position control of the crt display. The outer control is a course adjustment and the inner control is a fine adjustment.
5. mρ/DIV	Selects the vertical deflection factor—5mρ/div to 500 mρ/div (5-2-1 sequence).
6. POWER	Push-off, pull-on switch—does not affect the battery charging circuit.
7. GAIN	Screwdriver adjust to set the gain of the vertical amplifier.
8. NOISE FILTER	Reduces displayed noise. Display rate is reduced by a factor of 10.
9. BATTERY	Meter to indicate the relative charge of the power pack.
10. ZERO REF CHECK	Momentary contact pushbutton. When pushed, checks the horizontal location of the incident pulse on the crt when the DISTANCE dial is being used.
11. ZERO REF SET	Horizontal pulse position control for crt display. Sets the incident pulse edge to a vertical reference line of the crt when the DISTANCE dial is at 000 or the ZERO REF CHECK button is pushed.
12. MULTIPLIER	Two-position switch (red control) for X.1 or X1 multiplier. Affects both the DISTANCE dial and the FEET/DIV (METRES/DIV) control.
13. DISTANCE	Indicates the distance from the 1502 to the point on the cable where the display window begins. Two ranges: 100 feet (25 m) at X.1 or 1000 feet (250 m) at X1. Disabled when the FEET/DIV (METRES/DIV) is at 200 (FIND) (50).
14. FEET/DIV (METRES/ DIV)	Selects the horizontal deflection factor: X1 = 1 – 200 ft/div (25 cm – 50 m/div). X.1 = 0.1 – 20 ft/div (2.5 cm – 5 m/div).
15. CABLE DIELECTRIC SOLID POLY SOLID PTFE OTHER VAR	Three pushbuttons and a screwdriver adjust. Selects the proper velocity of propagation. VAR from 0.55 to 1.0 when the OTHER pushbutton is pressed. Fully CW is for air dielectric. VAR control has reference marks every 30° to indicate relative propagation constants.
16. RECORD	Two-position lever switch; pushed up and then released, it initiates X-Y recorder or a chart recorder.
17. AC LINE FUSES	Protection fuses for line power and battery charging circuits (0.5 A fuses for 115 V ac; 0.3 A fuses for 230 V ac).

222.565

Figure 13-26.—1502 front panel controls.

13-27), which is contained in the operator's handbook that comes with the equipment.

Calibrated distance controls on the equipment allow an operator to examine up to 100 feet of cable with segments as small as one foot displayed horizontally across the ten-division CRT screen. Low-loss cables as long as 2,000 feet may be examined at 100 feet or 200 feet for each division. The horizontal CRT scale is calibrated directly in distance units from 0.1 foot for each division to 200 feet for each division. A three-digit direct reading dial (figure 13-26, item 13) indicates the distance to any cable discontinuity when you use the dial to horizontally position the discontinuity's reflection to a CRT reference line.

For proper operation and measurement concepts of the equipment, refer to the operator's handbook.

LASERS

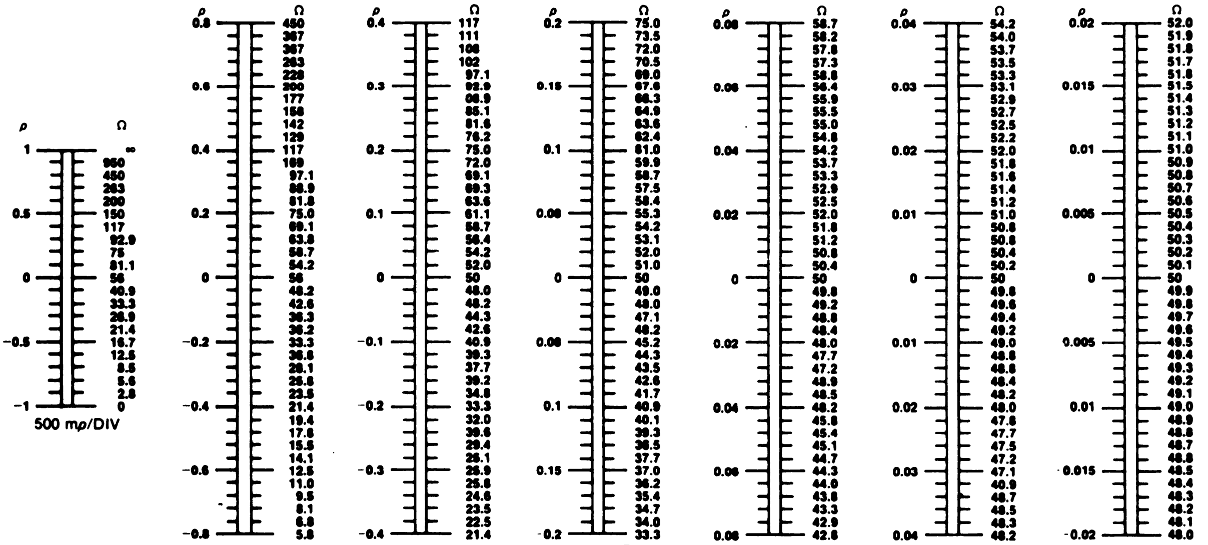
This section is an introduction to some of the problems peculiar to the maintenance of laser systems. The expanding use of laser systems in todays modern weapon systems makes it necessary for you to recognize problems peculiar to lasers.

SAFETY

The direct beam of a laser can cause severe eye damage. So can a reflected beam, even when the reflecting surface is not mirror bright.

Lasers are distinctly different from all previously known sources of light, both in the way they generate light and in the nature of the light they produce. Coherence gives the laser many of its unique capabilities. The output of even a weak laser (output of 1 joule) can be 100,000 times as intense as the surface of the sun. A laser which has an output of 500 joules would be 50 million times as intense as the surface of the sun.

Lasers can apply energy at the rate of several million watts per square centimeter. Even in the form of a brief pulse, this energy tends to cause rather drastic physical effects. It is not surprising, therefore, that the intense energy levels available



DIRECTIONS FOR USE: LOCATE THE COLUMN OVER THE SETTING OF THE mρ/DIV SWITCH. FIND THE ρ VALUE ON THE LEFT SIDE OF THE COLUMN AND READ THE IMPEDANCE ON THE RIGHT SIDE CORRESPONDING TO THE ρ VALUE.

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222.566

Figure 13-27.—Impedance nomograph.

do create biological effects. Despite the uncertainty about specific exposure limits, it is possible to establish safety rules for avoidance of potential hazards.

The beam from a laser does not obey the inverse-square law. While the intensity of a laser beam does decrease with distance, the rate is not so rapid as that of conventional sources. Divergence of the beam from a laser occurs very slowly. For example, a laser beam having a diameter of 1 centimeter when it emerges from the laser increases to only 2 centimeters at a distance of 10 meters. The energy is contained in only a 4-centimeter diameter at twice that distance. Since the beam spreads so slowly, *distance is not a satisfactory safeguard.*

When a laser beam bounces off a reflector, it normally spreads over a larger solid angle than the original beam. The energy in a given area of the beam thus becomes less as the distance from the reflector increases. This effect suggests that the farther away from the scatterer (reflector) the observer is, the less the danger of eye damage. However, the cornea of the eye focuses distant objects to a smaller size on the retina than near objects. Thus, while the energy entering the cornea is less for distant objects, the energy density at the retina can be higher. It is, in fact, true that for a given laser spot size on the scatterer, the energy density at the retina can be critical at one distance and less than critical at a shorter distance.

The following general practices should always be observed to minimize the danger presented by laser devices. This is not a complete list by any means. If you are assigned to a laser system, ensure that you obtain and observe all additional precautions.

1. Use laser equipment properly.

2. Know laser hazards.

3. Laser research laboratory areas and maintenance shops are closed areas.

4. Wear goggles or filter-type goggles when working with lasers.

5. Do NOT look directly at an operating laser or its reflection in any type of operation.

6. Avoid all contact between the skin and the laser beam.

7. Report any concern or anxiety about possible or existing exposure to laser radiation to appropriate medical personnel.

8. Do not look directly at the pump source.

9. Use countdown procedures.

10. A minimum of two people must be present when the laser is operating.

11. Identify laser areas properly (see figure 13-28).

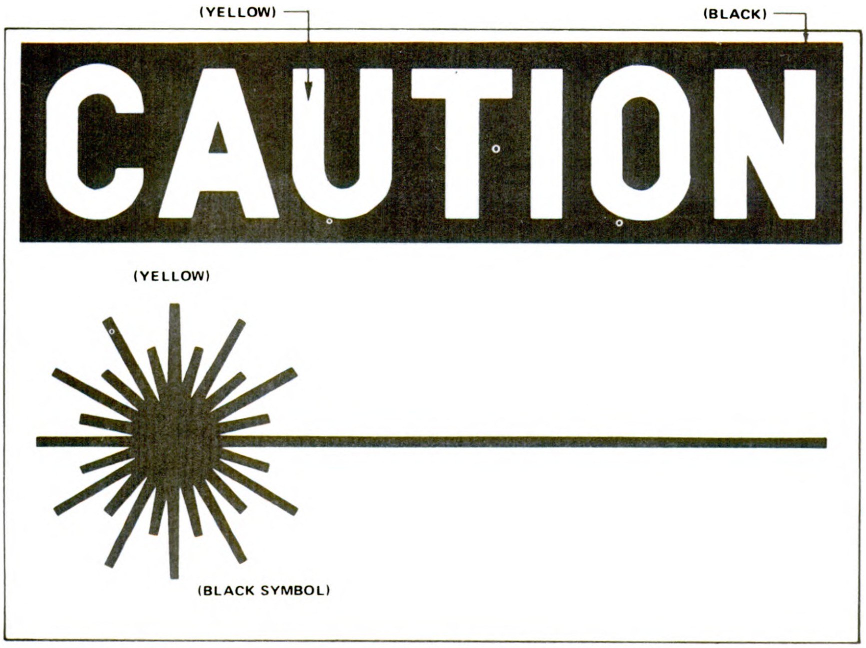
MAINTENANCE

A typical laser system is shown in figure 13-29. It consists of the following parts: laser rangefinder designator with separate transmitter and receiver, forward air controller receiver, and various power supplies and electronics (not shown in this figure).

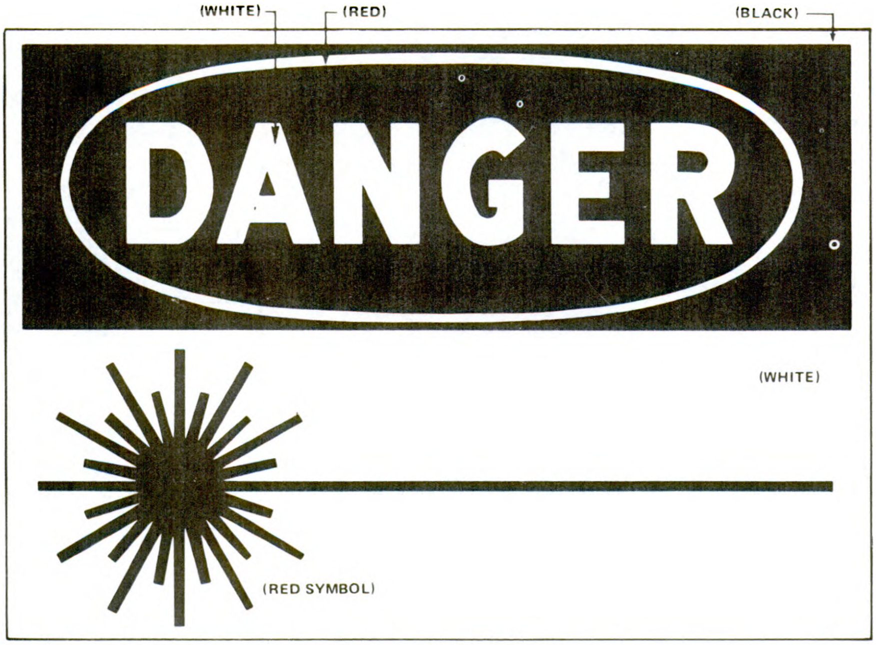
Like any avionics system, this system has its own unique maintenance and servicing characteristics, such as gas servicing and lens maintenance. When you perform maintenance on lasers, refer to the proper MIM. Also, there should be adequate supervision before any maintenance is performed on a laser system.

Laser systems have several interlocks built in. Interlocks are simple switches and relays, such as a weight-on-wheels switch. They provide a safeguard so that maintenance personnel will not accidently operate the equipment on the ground when maintenance is being performed. Often, it is necessary to override these interlocks while performing specific maintenance and accomplishing performance checks. After maintenance is completed, be sure that you replace these interlocks in the proper working order to ensure personnel safety and proper operation of the system.

Laser systems often have high pressure servicing equipment to ensure the proper amount laser gas is present in the system. A typical



(A) CLASS 2 AND 3 LASERS



(B) CLASS 4 LASER

Figure 13-28.—Warning signs for class 2, 3, and 4 lasers.

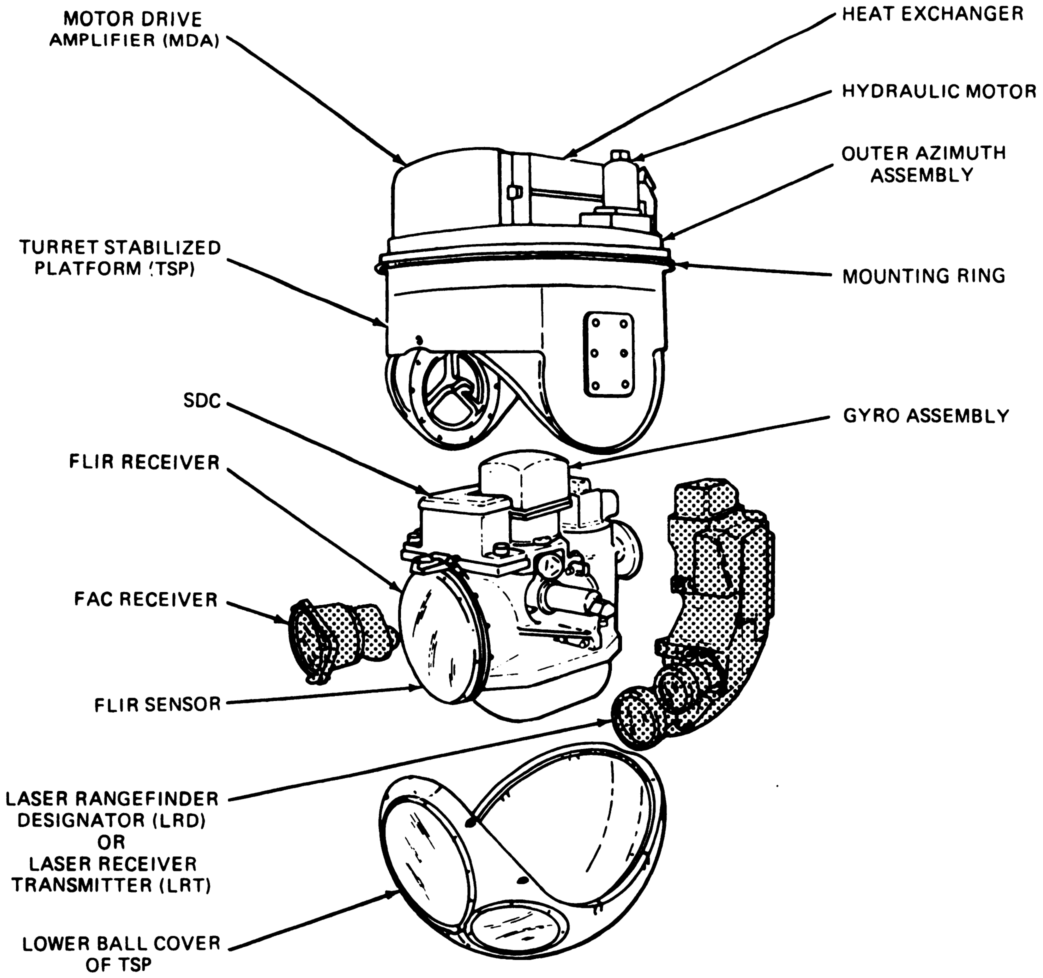


Figure 13-29.—A typical laser system.

kit is shown in figure 13-30. Proper use of this type of equipment is essential for personnel safety. Also, if the equipment is properly used, damage to expensive weapon systems is avoided. Before you service any lasers or associated equipment, consult the proper MIM.

SUMMARY

In this chapter, we discussed some of the problems encountered during and peculiar to radar maintenance. We discussed the importance of a radar operating at its peak efficiency to obtain maximum range and target resolution. Some radar systems have a built-in-test (BIT) feature that requires no test equipment to check out the entire radar system. We discussed the use and importance of time-domain reflectometers (TDR) and pointed out the time a technican can save when properly trained in these test sets. We also discussed the use of VAST and mini-SACE to check out weapon replaceable assembly (WRA) once removed from the aircraft.

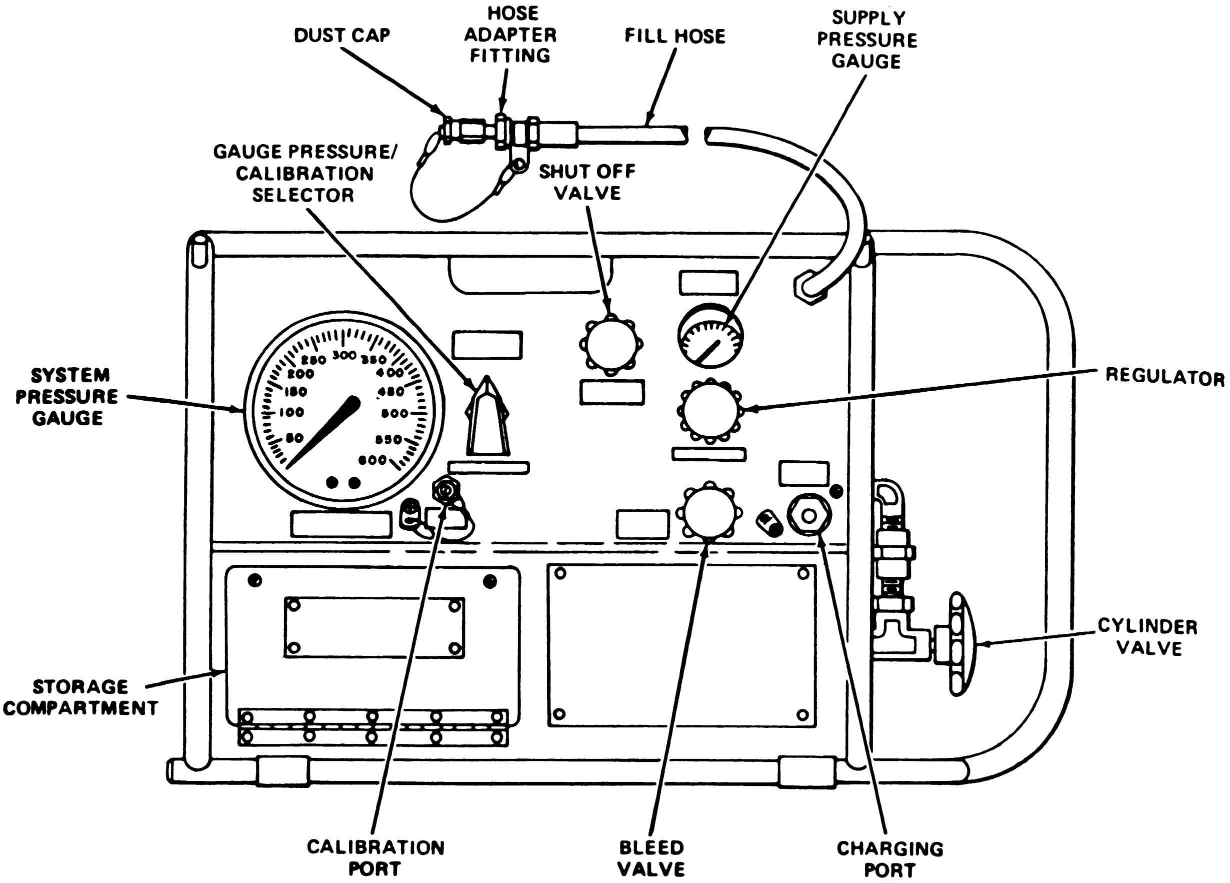


Figure 13-30.—Laser gas pressurization kit.

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NONRESIDENT CAREER COURSE

AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2

NAVEDTRA 10387-D

Prepared by the Naval Education and Training Program Development
Center, Pensacola, Florida

Your NRCC contains a set of assignments and perforated answer sheets. The Rate Training Manual, AVIATION FIRE CONTROL TECHNICIAN 3&2, Part 2 NAVEDTRA 10387-D, is your textbook for the NRCC. If an errata sheet comes with the NRCC, make all indicated changes or corrections. Do not change or correct the textbook or assignments in any other way.

HOW TO COMPLETE THIS COURSE SUCCESSFULLY

Study the textbook pages given at the beginning of each assignment before trying to answer the items. Pay attention to tables and illustrations as they contain a lot of information. Making your own drawings can help you understand the subject matter. Also, read the learning objectives that precede the sets of items. The learning objectives and items are based on the subject matter or study material in the textbook. The objectives tell you what you should be able to do by studying assigned textual material and answering the items.

At this point you should be ready to answer the items in the assignment. Read each item carefully. Select the BEST ANSWER for each item, consulting your textbook when necessary. Be sure to select the BEST ANSWER from the subject matter in the textbook. You may discuss difficult points in the course with others. However, the answer you select must be your own. Remove a perforated answer sheet from the back of this text, write in the proper assignment number, and enter your answer for each item.

Your NRCC will be administered by your command or, in the case of small commands, by the Naval Education and Training Program Development Center. No matter who administers your course you can complete it successfully by earning a 3.2 for each assignment. The unit breakdown of the course, if any, is shown later under Naval Reserve Retirement Credit.

WHEN YOUR COURSE IS ADMINISTERED BY LOCAL COMMAND

As soon as you have finished an assignment, submit the completed answer sheet to the officer designated to grade it. The graded answer sheet will not be returned to you.

If you are completing this NRCC to become eligible to take the fleetwide advancement examination, follow a schedule that will enable you to complete all assignments in time. Your schedule should call for the completion of at least one assignment per month.

Although you complete the course successfully, the Naval Education and Training Program Development Center will not issue you a letter of satisfactory completion. Your command will make an entry in your service record, giving you credit for your work.

WHEN YOUR COURSE IS ADMINISTERED BY THE NAVAL EDUCATION AND TRAINING PROGRAM DEVELOPMENT CENTER

After finishing an assignment, go on to the next. Retain each completed answer sheet until you finish all the assignments in a unit (or in the course if it is not divided into units). Using the envelopes provided, mail your completed answer sheets to the Naval Education and Training Program Development Center where they will be graded and the score recorded. Make sure all blanks at the top of each answer sheet are filled in. Unless you furnish all the information required, it will be impossible to give you credit for your work. The graded answer sheets will not be returned.

The Naval Education and Training Program Development Center will issue a letter of satisfactory completion to certify successful completion of the course (or a creditable unit of the course). To receive a course-completion letter, follow the directions given on the course-completion form in the back of this NRCC.

You may keep the textbook and assignments for this course. Return them only in the event you disenroll from the course or otherwise fail to complete the course. Directions for returning the textbook and assignments are given on the book-return form in the back of this NRCC.

PREPARING FOR YOUR ADVANCEMENT EXAMINATION

Your examination for advancement is based on the Occupational Standards for your rating as found in the MANUAL OF NAVY ENLISTED MANPOWER AND PERSONNEL CLASSIFICATIONS AND OCCUPATIONAL STANDARDS (NAVPERS 18068). These Occupational Standards define the minimum tasks required of your rating. The sources of questions in your advancement examination are listed in the BIBLIOGRAPHY FOR ADVANCEMENT STUDY (NAVEDTRA 10052). For your convenience, the Occupational Standards and the sources of questions for your rating are combined in a single pamphlet for the series of examinations for each year. These OCCUPATIONAL STANDARDS AND BIBLIOGRAPHY SHEETS (called Bib Sheets), are available from your ESO. Since your textbook and NRCC are among the sources listed in the bibliography, be sure to study both as you take the course. The qualifications for your rating may have changed since your course and textbook were printed, so refer to the latest edition of the Bib Sheets.

NAVAL RESERVE RETIREMENT CREDIT

This course is evaluated at 12 Naval Reserve retirement points which will be credited upon satisfactory completion of the entire course. These points are creditable to personnel eligible to receive them under current directives governing the retirement of Naval Reserve personnel.

COURSE OBJECTIVE

In completing this NRCC, you will demonstrate a knowledge of the subject matter by correctly answering questions on the following: handtools and materials, servosystems, data sensing elements, weapon control fundamentals, the bombing problem, radar circuits, weapons control radar, principles of navigation, electrooptical sight systems, electrical power and ground cooling systems, television, and avionics maintenance.

While working on this Nonresident Career Course, you may refer freely to the text. You may seek advice and instruction from others on problems arising in the course, but the solutions submitted must be the result of your own work and decisions. You are prohibited from referring to or copying the solutions of others, or giving completed solutions to anyone else taking the same course.

Naval courses may include a variety of questions -- multiple-choice, true-false, matching, etc. The questions are not grouped by type; regardless of type, they are presented in the same general sequence as the textbook material upon which they are based. This presentation is designed to preserve continuity of thought, permitting step-by-step development of ideas. Some courses use many types of questions, others only a few. The student can readily identify the type of each question (and the action required) through inspection of the samples given below.

MULTIPLE-CHOICE QUESTIONS

Each question contains several alternatives, one of which provides the best answer to the question. Select the best alternative, and blacken the appropriate box on the answer sheet.

SAMPLE

s-1. The first person to be appointed Secretary of Defense under the National Security Act of 1947 was
1. George Marshall
2. James Forrestal
3. Chester Nimitz
4. William Halsey

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-1	☐	■	☐	☐	___

TRUE-FALSE QUESTIONS

Mark each statement true or false as indicated below. If any part of the statement is false the statement is to be considered false. Make the decision, and blacken the appropriate box on the answer sheet.

SAMPLE

s-2. Any naval officer is authorized to correspond officially with any systems command of the Department of the Navy without his commanding officer's endorsement.

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-2	☐	■	☐	☐	___

MATCHING QUESTIONS

Each set of questions consists of two columns, each listing words, phrases or sentences. The task is to select the item in column B which is the best match for the item in column A that is being considered. Items in column B may be used once, more than once, or not at all. Specific instructions are given with each set of questions. Select the numbers identifying the answers and blacken the appropriate boxes on the answer sheet.

SAMPLE

In questions s-3 through s-6, match the name of the shipboard officer in column A by selecting from column B the name of the department in which the officer functions.

A

s-3. Damage Control Assistant

s-4. CIC Officer

s-5. Disbursing Officer

s-6. Communications Officer

B

1. Operations Department
2. Engineering Department
3. Supply Department

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-3	☐	■	☐	☐	___
s-4	■	☐	☐	☐	___
s-5	☐	☐	■	☐	___
s-6	■	☐	☐	☐	___

Assignment 1

Aviation Fire Control Technician Rating and Handtools and Materials

Text: Pages 1-1 through 2-34

In this course you will demonstrate that learning has taken place by correctly answering training items. The mere physical act of indicating a choice on an answer sheet is not in itself important; it is the mental achievement, in whatever form it may take, prior to the physical act that is important and toward which course learning objectives are directed. The selection of the correct choice for a course training item indicates that you have fulfilled, at least in part, the stated objective(s).

The accomplishment of certain objectives, for example, a physical act such as drafting a memo, cannot readily be determined by means of objective type course items; however, you can demonstrate by means of answers to training items that you have acquired the requisite knowledge to perform the physical act. The accomplishment of certain other learning objectives, for example, the mental acts of comparing, recognizing, evaluating, choosing, selecting, etc., may be readily demonstrated in a course by indicating the correct answers to training items.

The comprehensive objective for this course has already been given. It states the purpose of the course in terms of what you will be able to do as you complete the course.

The detailed objectives in each assignment state what you should accomplish as you progress through the course. They may appear singly or in clusters of closely related objectives, as appropriate; they are followed by items which will enable you to indicate your accomplishment.

All objectives in this course are learning objectives and items are teaching items. They point out important things, they assist in learning, and they should enable you to do a better job for the Navy.

This self-study course is only one part of the total Navy training program; by its very nature it can take you only part of the way to a training goal. Practical experience, schools, selected reading, and the desire to accomplish are also necessary to round out a fully meaningful training program.

Learning Objective: Recognize paths of advancement for the AQ and the requirements for each advancement.

1-1. The minimum requirements for each rate and rating can be found in what publication?

1. NAVPERS 18068 (Series)
2. NAVPERS 13048 (Series)
3. NAVPERS 16163 (Series)
4. NAVPERS 10054 (Series)

1-2. The AQ rating is included in the what Navy occupational field?

1. 1
2. 2
3. 3
4. 5

1-3. What publication contains detailer information about assignments to instructor duty?

1. NAVPERS 18068 (Series)
2. NAVPERS 15909 (Series)
3. NAVPERS 10319 (Series)
4. NAVPERS 16531 (Series)

1-4. Which of the following pay grade(s) are exempt from the (PAR) program?

1. E-7
2. E-8
3. E-9
4. Both 2 and 3 above

1-5. Which section on a PAR lists the occupational and military requirements for an AQ?

1. I
2. II
3. III
4. IV

1-6. Which of the following publications describes the PQS program?

1. OPNAV 3506.35
2. OPNAV 3500.61
3. OPNAV 3600.61
4. OPNAV 3500.34

1-7. What series of the PQS contains material on theory?

1. 100
2. 200
3. 300
4. 400

1-8. What series of the PQS contains material on qualification cards?

1. 100
2. 200
3. 300
4. 400

Learning Objective: Recognize safety practices and the purposes and uses of tools.

1-9. Within most work areas, what is the greatest single cause of accidents to personnel or damage to tools?

1. Fear of power tools
2. Working too fast
3. Lack of care
4. Improper use of tools

1-10. A center punch may be used for which of the following purposes?

1. To remove bolts
2. For marking extremely hard metals
3. For marking the center of a hole
4. To enlarge holes

1-11. When drilling metals, you should NOT use which of the following tools to hold the material?

1. The bench vise
2. The C clamp
3. The hand screw clamp
4. The hand

1-12. Which of the following is a characteristic of the Reed and Prince screwdriver?

1. 30-degree flukes
2. 45-degree flukes
3. Blunt end
4. Beveled walls

1-13. Which of the following conditions does NOT require the use of a nonmagnetic tool?

1. Where the disturbance of magnetic fields is undesirable
2. Where the introduction of magnetic fields should be avoided
3. Where strong magnetic fields can cause undersirable magnetism in other types of tools
4. Where magnetic fields are insignificant or negligible

1-14. A screwdriver that is fitted with insulated sleeving on the shank should be used only on which of the following circuits?

1. Low voltage
2. High voltage
3. High-power RF
4. Medium voltage

1-15. Under which of the following conditions should you use a torque wrench?

1. When a thread lubricant is required
2. When a definite amount of twisting force to a nut or bolt head is required
3. When sufficient torque to break loose previously tightened bolts or nuts must be applied
4. When the maximum amount of twisting force must be applied to break loose previously tightened bolts or nuts

1-16. The desired amount of torque is preset before using which of the following types of torque wrenches?

1. Deflecting-beam
2. Dial-indicating
3. Micrometer-indicating
4. Micrometer-setting

1-17. You are demonstrating the proper use and care of a micrometer-setting torque wrench when you follow which of the following procedures?

1. Store it in your toolbox
2. Check its calibration at least monthly
3. Use it to break loose bolts
4. Set it to its highest setting before returning it to storage

1-18. What method should you use to clean a dirty contact point?

1. Burnish with a burnishing tool only
2. Rub with a fine abrasive, and then burnish with a burnishing tool
3. Burnish with a burnishing tool, and then dust with the fingers
4. Rub with fine emery cloth, and then burnish with a burnishing tool

1-19. The recommended treatment of a relay on which one or more of the contacts are pitted is to

1. clean the points with alcohol, and then burnish them with a burnishing tool
2. burnish the points with a burnishing tool only
3. smooth the points with emery cloth, and then burnish them with a burnishing tool
4. replace the relay

1-20. Which of the following is an advantage of using the taper-pin electrical connector rather than the conventional type connector?

1. The crimp-on wire attachment makes soldering unnecessary
2. The connector wire does not require repairs
3. The wire connection to the pin and the pin connection to the connector are made simultaneously
4. The pin connection to the connector is soldered

1-21. The pull test spring of a taper pin insertion and removal tool is calibrated at a pulling force which presents which of the following indications?

1. The force necessary to remove the pin
2. The percentage of metal-to-metal contact between the pin and the connector
3. The proper pin insertion without actually removing the pin
4. The 100 percent pull test before the tool is disengaged

1-22. Potting compound is applied to the jaws of diagonal pliers for which of the following purposes?

1. To prevent short wires from dropping or flying after snipping
2. To firmly grip pin punches and center punches
3. To electrically insulate pliers
4. To clamp small work in a manner similar to vise-grip pliers

1-23. Safety wire pliers should NOT be used to perform which of the following functions?

1. Cutting
2. Holding
3. Stripping
4. Twisting

1-24. To ensure that the conductor is not damaged when using the wire and cable stripping tool, you should take which of the following actions?

1. Insert the wire in the smallest groove of the tool
2. Insert the wire so the jaws of the tool clamp the end to be stripped
3. Insert the wire in the proper groove of the tool
4. Insert the wire in the largest groove of the tool

1-25. Refer to figure 2-8. Where does the type MS 25037-1 crimping tool crimp the terminal lug?

1. Around the bare wire only
2. Around the insulation only
3. Around both the bare wire and the insulation
4. On the surface which extends beyond the guard

1-26. Prior to crimping a terminal to a wire using the MS 25037-1 crimping tool, you should ensure that which of the following conditions exist?

1. A No.34 drill rod will enter the smaller (red or blue) nest when the tool is fully closed
2. The guard is in position when crimping splices
3. A No. 36 drillrod will enter the smaller (red or blue) nest when the tool is fully closed
4. The guard is in a position which prevents the terminal from being inserted from the wrong side of the tool

1-27. When using the MS 3191-3 crimping tool, which of the following conditions is NOT related to obtaining a properly crimped terminal and wire?

1. The crimped indents must be positioned between the inspection hole and the front end of the insulation support
2. The correct selection must be made on the positioner head and indentor gap selector plate
3. The insulation must be inside the insulation support and the contact must not be bent
4. The crimped indents must be positioned between the positioner head and indentor gap

---

Learning Objective: Identify types of soldering equipment, soldering techniques, and maintenance aids.

1-28. What type of soldering tool should you use when removing a transistor?

1. A high-wattage soldering iron
2. A pencil-type soldering iron
3. A soldering gun
4. A resistance soldering unit

1-29. Which of the following groupings lists the principal advantages of a soldering gun?

1. Fast heating and cooling, low oxidation, easy tip tinning, low-cost replacement tips
2. Fast heating, high maximum temperature, easy tip cleaning
3. Fast heating and cooling, large amount of heat available, easy tip tinning, positive temperature regulation
4. Fast heating and cooling, alternating or direct current operation, easy tip cleaning, easily regulated temperature

1-30. Of the following methods, which one should you use to keep the soldering tip clean and well tinned?

1. The filing method
2. The dry cloth method
3. The dry sponge method
4. The damp sponge method

1-31. The double-tipped probes of a resistance soldering unit are especially useful for

1. soldering high resistance material
2. soldering cables to AN plugs and small connectors
3. melting connector inserts
4. burning wire insulation

1-32. Mechanical fingers may be used for which of the following purposes?

1. As a substitute for pliers
2. As a tool for bending metal for airframe repair
3. To safety wire designated parts of an installation
4. To retrieve small objects from places that are inaccessible by hand

1-33. To make a measurement with a steel scale, you should take the reading with the scale in what position?

1. Set on its edge on the surface being measured
2. Set at 180 degrees from the objects being measured
3. Set flat against the object being measured
4. Set on its end on the surface being measured

1-34. A complete, standard Navy two-cell flashlight contains which of the following parts?

1. A red lens only
2. A spare bulb only
3. Rubber seals in both ends and a red lens only
4. Rubber seals in both ends, a red lens, and a spare bulb

Learning Objective: Recognize publications, responsibilities, and procedures related to tool control.

1-35. Which of the following numbers identifies the NAVAIR allowance list that should be used to determine the types and numbers of tools allowed in the AQ work center?

1. 00-35QG-014
2. 00-35QG-015
3. 00-35QG-016
4. 00-35QG-020

1-36. Which of the following responsibilities should NOT be given to squadron central toolroom personnel?

1. Issuing tools
2. Storing tools
3. Discarding tools
4. Inventorying tools

1-37. Activities without central toolrooms may require what work center to maintain tool inventory responsibilities within the activity?

1. Production control
2. Material control
3. Quality assurance
4. Maintenance control

1-38. In a fleet squadron that does not have a central toolroom, what person/work center is responsible for ordering replacement tools?

1. The material control work center
2. The work center that lost the tool
3. The individual that lost the tool
4. The maintenance officer

1-39. During a toolbox inventory, any shortages are reported to the

1. maintenance officer via the work center supervisor and maintenance control
2. maintenance officer via the work center supervisor and QA/analysis
3. central toolroom via QA/analysis
4. center toolroom via the maintenance officer

Learning Objective: Identify fasteners and the conditions for reusing mounting hardware.

1-40. Which of the following guidelines applies to the reuse of mounting hardware items?

1. The items fulfill the specifications for their intended use
2. The items have minor discrepancies
3. Their reuse is not prohibited by existing directives
4. Their use is unrestricted if remounted on the same aircraft

1-41. One type of fastener that provides quick opening of access panels is the

1. Torq-Set screw
2. self-tapping screw
3. turnlock fastener
4. machine screw

1-42. Conventional screws are being replaced with Torq-Set machine screws by some manufacturers for which of the following reasons?

1. Their shear strength is higher
2. They are less susceptible to torque damage
3. Their holding quality per head area is better
4. They inflict less torque damage to the structure on which they are used

1-43. The use of proper torque in tightening nuts and bolts provides for which of the following results?

1. The possibility of structural failure due to fatigue
2. Minimum utilization of the potential strength of the structure being repaired
3. Alignment of cotter pin holes with the structure
4. Protection against structural fatigue

Learning Objective: Recognize the characteristics of connectors.

In answering items 1-44 through 1-46, select from column B the shell type indicator of the shell design found in column A.

	A. Designs	B. Indicators
1-44.	Solid shell	1. K
1-45.	Sealed construction	2. F
1-46.	Vibration resistant	3. D
		4. A

In answering items 1-47 through 1-49, select from column B the shell type indicator of the shell design found in column A.

	A. Designs	B. Indicators
1-47.	Split shell	1. B
1-48.	Flame barrier shelf	2. C
		3. E
1-49.	Pressurized type	4. H

● In answering items 50 through 52, refer to connector part number MS 3101-F-14-11-SX.

1-50. What does the letter F represent?

1. The shell type
2. The shell size
3. A flame barrier shell
4. A vibration resistant shell

1-51. What does the letter S indicate about the insert?

1. It is a pin insert
2. It is a socket insert
3. It has a single contractor
4. It has a screw arrangement

1-52. The letter X refers to which of the following factors of the shell?

1. Insert position
2. Type of insert
3. Shell design
4. Insert arrangement

1-53. Which of the following series of coaxial connectors is used where impedance matching is necessary?

1. SM
2. BNC
3. AT
4. TK

1-54. What feature of the TNC connector makes it preferred over the BNC connector where extreme vibration is present?

1. Its potting compound shock-absorbent filling
2. Its shatterproof insert-holding material
3. Its threaded coupling
4. Its bayonet-locking coupling

1-55. The dielectric material of a flexible coaxial cable usually consists of

1. Teflon
2. polyethylene
3. chloroprene
4. synthetic resin

1-56. Which of the following dielectric material is especially resistant to high temperature?

1. Teflon
2. Neoprene
3. Chloroprene
4. Polyethylene

1-57. At approximately what frequency must flexible coaxial cable be replaced with rigid coaxial cable?

1. 10 MHz
2. 3000 MHz
3. 100 KHz
4. 1000 KHz

Learning Objective: Recognize facts relevant to maintenance and to material responsibility and control.

1-58. Which of the following statements pertaining to the selection of substitute anchor nuts and washers is correct?

1. The substitute anchor nut thread may be different than the one prescribed, and the washer must have the same inner diameter as the one prescribed
2. The substitute anchor nut thread must be the same as the one prescribed and the washer must have the same inner diameter as the one prescribed
3. The substitute anchor must be the same size as the one prescribed, and the washer must have the same outer diameter as the one prescribed
4. Its electrical conductive quality is reduced to a harmless level if the visible residue is removed

1-59. In which of the following ways does soldering flux aid the soldering process?

1. It prevents rosin form adhering to the metallic surface
2. It removes oxide from the metallic surface
3. It cleans the surfaces to be soldered
4. It prevents solder from adhering to the soldering gun

1-60. Rosin-based flux is acceptable for use in electronics work for which of the following reasons?

1. Rosin is noncorrosive if neutralized
2. Its corrosive period is brief and the resulting damage is minimal
3. Rosin is noncorrosive and electrically nonconductive
4. Its electrical conductive quality is reduced to a harmless level if the visible residue is removed

1-61. What feature can you identify by the color of potting compound?

1. The moisture sealing quality of the compound
2. The curing time during which the compound must not be disturbed
3. the use of the compound in electrical connectors or relays
4. The temperature range in which the compound is usable

Learning Objective: Recognize procedures and publications for identifying material requirements.

1-62. An item of supply is considered to be positively identified when the item is identified to its

1. proper nomenclature
2. part number
3. national stock number
4. manufacturer's code

1-63. Which of the following is the primary purpose of maintenance instruction manuals (MIMs)?

1. To provide national stock numbers
2. To provide system standards
3. To provide maintenance information
4. To provide part numbers

1-64. The illustrated parts breakdown (IPB) manual for each model aircraft is prepared by

1. NAVAIR
2. NAVAIRSYSCOM
3. the manufacturer of the aircraft
4. the aviation supply officer

1-65. Initial outfitting lists (IOL), allowance lists (AL), and tables of basic allowances (TBA) are prepared by

1. NARF
2. NAVAIRSYSCOM
3. NAVPUBCEN
4. NAVELEX

1-66. Which of the following is the major difference between the weapons equipment list (WEL) and the identification list (IL)?

1. The WEL lists material by NSN and the IL lists material by part number
2. The WEL lists material by part number, and the IL lists material by NSN
3. The WEL lists material according to material type and the IL lists material according to aircraft type
4. The WEL lists material according to aircraft type, and the IL lists material by material type

1-67. What code/part number is used to correctly identify an item manufactured by an individual company?

1. The manufacturer's part number only
2. The federal supply code for manufacturers (FSCM) only
3. The manufacturer's part number and the federal supply code for manufacturers
4. The federal supply code for manufacturers and the national item identification number

1-68. What total number of digits make up a national stock number (NSN)?

1. 13
2. 11
3. 9
4. 7

Assignment 2

Servosystems and Data Sensing Elements

Text: Pages 3-1 through 4-7

Learning Objective: Recognize components and operating principles of servomechanisms including advantages and disadvantages of various types of error detectors.

2-1. A servomechanism is normally composed of a data transmission system, a servocontrol amplifier, and a/an

1. control transformer
2. servomotor
3. error signal generator
4. correction signal generator

2-2. Refer to figure 2-1. This figure shows that the error signal is proportional to the signal of the

1. input less the signal of the output
2. output divided by the signal of the input
3. input divided by the signal of the output
4. output less the signal of the input

2-3. What component of the data transmission system compares the input with the output of the servomechanism?

1. Servomotor
2. Servo followup
3. Error detector
4. Servoamplifier

2-4. What error detector device should be used to develop either an ac or a dc output voltage?

1. E-transformer
2. Potentiometer
3. Fluxgate
4. Control transformer

2-5. Refer to figure 3-2. When the input shaft is rotated, an error voltage is applied to the

1. servo-control amplifier
2. error reducer
3. input potentiometer
4. load

2-6. When an E-transformer is being used as an error detector, the secondary windings are connected in which of the following configurations?

1. In series-opposing
2. In parallel
3. In series-aiding
4. In series-parallel

2-7. Which of the following is a disadvantage of using an E-transformer as a servo-error detector?

1. It has poor accuracy
2. It is of large size
3. It uses excess electrical power
4. It allows only limited input motion

2-8. Which of the following is the main advantage of using a synchro control transformer as an error detector?

1. It has high accuracy
2. Its driving torque requirements are small
3. Its noise level is low
4. Its input and output rotation angles are unlimited

2-9. Which of the following values of an ac input signal will a servomotor follow?

1. The average value
2. The instantaneous value
3. The effective value
4. Either 2 or 3 above, depending upon input signal phase with respect to the reference signal

2-10. The synchro data transmission system is composed of a synchro transmitter, a synchro control transformer, and sometimes includes a

1. servomotor
2. dc amplifier
3. potentiometer detector
4. differential transmitter

2-11. The stator of a synchro transmitter consists of three coils which are displaced from each other by

1. 90 degrees physically
2. 90 degrees electrically
3. 60 degrees physically
4. 120 degrees electrically

2-12. When its rotor and stator windings are aligned, a synchro differential transmitter is comparable to a

1. step-up transformer
2. step-down transformer
3. one-to-one ratio transformer
4. deflection transformer

2-13. What type of error detector uses the horizontal component of the earth's magnetic field to produce an output signal?

1. E-transformer
2. Synchro device
3. Potentiometer
4. Fluxgate

Learning Objective: Identify operating uses, principles, and design features of multiple-speed data transmission system.

● Refer to figure 3-8 in answering items 2-14 and 2-15.

2-14. A multiple-speed data transmission system is used in conjunction with a single-speed system in a servomechanism for what purpose?

1. To compensate for a wide range of rotation rates
2. To step down the frequency of the error signal
3. To eliminate the necessity of a servo-control amplifier in the system
4. To increase the accuracy of control of the servomotor's load

2-15. In a combination 1-speed and 23-speed data transmission system, a 1-degree error is present in the 1-speed synchro system. What degree of servo error would be introduced by the 23-speed data transmission system?

1. 1/23°
2. 1/2 °
3. 1°
4. 23°

2-16. In order to eliminate the possibility of false null positions in a multiple-speed data transmission system, the system should be designed to contain a high-speed synchro whose speed is maintained at which of the following rates?

1. At an odd multiple of the system's low-speed synchro
2. At least twice the speed of the system's low-speed synchro
3. At 10 times the speed of the system's low-speed synchro
4. At a constant speed set higher than the system's low-speed synchro

Learning Objective: Identify operating principles and characteristics of circuits and components of servocontrol systems.

2-17. Which of the following is a characteristic of a servoamplifier?

1. Low gain only
2. A large constant phase shift only
3. A low gain and a large constant phase shift
4. A low output impedance

2-18. In order to use an ac servoamplifier instead of a dc servoamplifier in a servosystem which uses a dc voltage for the error signal, the system must include what device?

1. A damper
2. A phase-sensitive modulator
3. A demodulator
4. A phase detector (in the modulator output circuit)

2-19. Refer to figure 3-10. Relative to polarity, amplitude, and phase, what change occurs to an error signal in a vibrator modulator?

1. Amplitude changes to phase
2. Phase changes to amplitude
3. Polarity changes to phase
4. Phase changes to polarity

2-20. A device which enables ac signals to control a dc servomotor is known as a

1. demodulator
2. servoamplifier
3. control transformer
4. differential transmitter

- Refer to figure 3-12 in answering items 2-21 and 2-22.

2-21. What potential appears at the output of a bridge phase detector when only the reference voltage is applied?

1. Zero voltage
2. AC reference voltage
3. Steady dc voltage
4. Varying dc voltage

2-22. The magnitude and polarity of the output voltage at point E are dependent of which of the following factors?

1. Conduction of CR3 and CR1
2. Conduction of CR4 and CR2
3. Amplitude and phase of the error signal
4. Amplitude and phase of the reference voltage

2-23. What is the principal difference between a bridge phase detector and a triode phase detector?

1. The triode phase detector produces an ac output voltage
2. The triode phase detector does not require a reference signal
3. The triode phase detector produces an output signal whose amplitude is proportional to the amplitude of the input signal
4. The triode phase detector provides amplification of the input signal

2-24. Refer to figure 3-13. If there were no error voltage applied to T2, what would be the exciter field's flux intensity?

1. Varying
2. Maximum
3. Minimum
4. Steadily increasing

2-25. Refer to figure 3-15. The magnetic amplifier contains a transformer and which of the following components?

1. Six reactors
2. Two reactors, each having three windings
3. Three reactors, each having two windings
4. Four reactors, two of which have two windings

2-26. An amplifier integrator circuit in a servosystem reduces system error by

1. developing a signal proportional to the integral of the error
2. developing a signal proportional to the error
3. reducing shaft driving torque
4. increasing positional displacement between input and output shafts

- Refer to figure 3-16 in answering items 2-27 and 2-28.

2-27. The output voltage which appears across the capacitor is

1. inversely proportional to the charging voltage
2. directly proportional to the charging voltage
3. inversely proportional to the integral of the charging current
4. directly proportional to the integral of the charging current

2-28. The ideal voltage output from the integrator resulting from application of a constant input signal is characterized as a voltage whose amplitude changes in which of the following ways?

1. Increases steadily
2. Decreases steadily
3. Remains constant in value
4. Drops slightly and then remains steady

Learning Objective: Identify types, operating principles, and characteristics of various output devices, including circuits and methods for bilateral control.

2-29. In a servosystem, which of the following is a function of the output device?

1. An error signal is provided to the amplifier
2. Control of the input controller is maintained
3. Mechanical motion is converted into power to drive the load
4. Electrical power is converted to mechanical power

2-30. Which of the following is a characteristic of ac servomotors?

1. Slow response time
2. Low reliability
3. Short brush life
4. Narrow speed range

2-31. What type of ac motor is most widely used as an ac servomotor?

1. Shunt
2. Split series
3. Split-phase ac
4. Two-phase induction

2-32. The turning force in a two-phase induction motor is obtained by means of

1. two rotating magnetic fields produced from two stationary field 90° out of phase
2. two rotating magnetic fields produced from two stationary fields 180° out of phase
3. one rotating magnetic field produced from two stationary fields 90° out of phase
4. one rotating magnetic field produced from two stationary fields 180° out of phase

2-33. What characteristic of a servomotor results in increased stability?

1. High starting torque
2. Simplicity and ruggedness
3. Limited rotation angle
4. Adaptability to bidirectional loops

2-34. Series dc motors require which of the following special circuits for bidirectional control?

1. An eddy current braking circuit
2. A current limiting circuit
3. A phase shifting circuit
4. A switching circuit

2-35. The direction of rotation of a shunt dc motor may be controlled by

1. varying the field current
2. connecting the field windings in parallel
3. reversing the direction of either the armature or field current
4. reversing the direction of both the armature and field currents

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Learning Objective: Recognize causes and definitions of servo errors, and identify operating principles and characteristics of error-reducing devices.

2-36. Hydraulic power devices, which are used frequently in servomechanisms of aircraft weapons systems, are characterized by which of the following factors?

1. Low speed of response, heavy load adaptability, and very high accuracy
2. Very high accuracy, heavy load adaptability, fast response, and ease of maintenance
3. Light weight, fast response, and ease of installation
4. Power amplification capability, low speed of response, low maintenance requirements, and no operational friction

2-37. Which of the following is a primary cause of servosystem oscillations?

1. Inertia
2. Friction
3. Low system gain
4. High system gain

2-38. What is the purpose of damping in any servomechanism?

1. To increase the error transient time
2. To decrease the width of the null
3. To provide steady-rate errors
4. To reduce oscillation

2-39. When just enough damping to prevent overshoot of the commanded position is applied to a servosystem, the system can be described as being in what condition?

1. Critically damped
2. Slightly overdamped
3. Slightly underdamped
4. Proportionally damped

2-40. What type of damper would absorb too much power from a servosystem?

1. Eddy current
2. Dry friction clutch
3. Pure viscous
4. Heavy flywheel

2-41. Error rate voltage is produced in a network by the tachometer error-rate damper by using a device which is essentially a generator that produces a steady-state voltage which is proportional to

1. the shaft rotation speed
2. changes in the damper's input voltage
3. the servomotor's torque
4. the current through the demodulator

2-42. Servo reponse error to a constant velocity input is known as

1. constant error
2. velocity error
3. inherent error
4. angle error

2-43. Refer to figure 3-21. The integrator circuit consisting of R2, R1, and C1 is designed so the transient error signal delivered to the amplifier is only that portion which is

1. developed across R2
2. developed across R2
3. the combination of the R1 and R2 voltages
4. the difference between the R1 and R2 voltages

2-44. Increasing the gain of the servoamplifier in a servosystem has which of the following effects?

1. Increases velocity errors in the system
2. Increases steady-state errors caused by restraining torques on the servo load
3. Decreases the speed of response to transient inputs
4. Increases the speed of response to transient inputs

2-45. In balancing a servosystem, the circuit is adjusted to obtain which of the following results?

1. Maximum output when no error signal is applied
2. Compensation for variations in-line voltage
3. Zero output when no signal is applied
4. The fastest response without hunting

Learning Objective: Recognize equipment and methods used to align synchro units.

2-46. When zeroing a mechanically driven synchro device, what method(s) is/are used?

1. Jumper
2. Voltmeter
3. Electrical lock and voltmeter
4. Jumper-electrical lock combination

2-47. In order to have a zero output from a control transformer, in what manner must the rotor winding be positioned with reference to the magnetic field of the stator?

1. Displaced by 120 degrees
2. Displaced by 240 degrees
3. Perpendicular
4. Parallel

2-48. Synchro alignment set TS-714/U can be used for which of the following purposes?

1. To check the alignment of synchros
2. To check the alignment of resolvers
3. Both 1 & 2 above

2-49. When the TSU-714/U synchro alignment set is used to zero a synchro or resolver, the correct null is indicated on the microammeter by which of the following readings?

1. The lower of the two nulls
2. The higher of the two nulls
3. Zero
4. Maximum deflection

Learning Objective: Recognize control adjustments and functions of various circuits and components of typical radar antenna positioning servosystems.

● Refer to figures 3-29 through 3-35 in answering items 2-50 through 2-59.

2-50. The antenna will begin a 7° conical sweeping pattern when which of the following actions occurs?

1. The radar is placed in the search mode
2. The target is bracketed with strobe lines only
3. The lock-on switch is depressed only
4. The target is bracketed with strobe lines and the lock-on switch is depressed

2-51. Refer to figure 3-31. In search operation, when does an error signal appear at the input to the servocontrol amplifier?

1. Only when the aircraft undergoes a change in attitude
2. Only when the control handle is repositioned for a change in antenna elevation
3. Constantly, unless the aircraft undergoes a change in attitude
4. Whenever the wiper of the input potentiometer is repositioned or the amplitude of voltage across it changes

2-52. Refer to figure 3-32. If the dot representing the antenna spin axis could be positioned to stay exactly on the target, what would be the input signal to the error amplifier?

1. A constant voltage
2. A 25-Hz sine wave
3. A varying positive voltage
4. A varying negative voltage

2-53. Refer to figure 3-33. During search mode operation, when does error detector potentiometer R3 apply an error signal to V1?

1. When the aircraft changes its elevation attitude
2. When the antenna reaches maximum scan to either side
3. When a new elevation is ordered by movement of the control handle
4. Each of the above

2-54. Compare figures 3-31 and 3-33. Which of the following components in figure 3-33 perform the functions of the error detector potentiometers in figure 3-31?

1. R1 and R2
2. R4 and R5
3. R3 and R35
4. R3 and the center-tapped potentiometer in the gyro stabilizer circuit

- In answering items 2-55 through 2-59 refer to figure 3-3.

2-55. The demodulator drive gain is stabilized by the action of what components in V4?

1. Grid-plate feedback loop only
2. The reference voltage across R35
3. Unbypassed cathode resistor only
4. Unbypassed cathode resistor in conjunction with the component in V4s grid-plate feedback loop

2-56. When a positive voltage is applied to the grid of V9, the resulting circuit action causes which of the following actions relative to the antenna?

1. The antenna's elevation angle to decrease only
2. The antenna's elevation angle to increase
3. Damping of antenna oscillations only
4. Damping of antenna oscillations and the antenna's elevation angle to decrease

2-57. When the tracking mode is selected, adjustment of R13 performs what function?

1. It compensates for any phase shift of error signal as the signal passes through the servoamplifier circuits
2. It improves the linearity of V2 by controlling the amount of degnerative feedback applied to V2's input circuit
3. It reduces any error signal to zero by supplying the correct amount of regenerative feedback to V2's cathode
4. It eliminates any phase shift or error signal caused by feed through from the gyro stabilizer or because of control handle movement

2-58. The function of the 50-Hz spin generator in the antenna servosystem is to furnish a reference voltage for the

1. modulator during both track and search operations
2. demodulator during track operation
3. demodulator during search operation
4. radar receiver during search operation

2-59. Which of the following is the first potentiometer to be adjusted in the alignment procedure?

1. Phase adjust R13
2. Gain adjust R20
3. Balance control R25
4. Bias adjust R30

2-60. Displacement of the spool valve from its centered position is the result of which of the following forces?

1. Tension differential between the centering springs
2. Mechanical movement between the flapper and the spool
3. Pressure differential between fluids in the right and left control areas
4. Pressure differential between fluids in the high and low pressure inputs

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Learning Objective: Recognize the terms, purposes, and principles of operation of accelerometers and gyroscopes in sensing acceleration, attitude, and direction.

2-61. Which of the following devices are used to sense changes in attitude, direction, and acceleration?

1. Motors and generators
2. Transistors and tubes
3. Synchros and regulators
4. Accelerometers and gyroscopes

2-62. Which of the following statements describes the action of an accelerometer's pendulous mass during periods of deceleration?

1. It tends toward the center
2. It tends to swing behind its center position
3. It tends to swing ahead of its center position
4. It tends to swing to the left or right

2-63. Which of the following statements is correct concerning the form of the outputs of a force balance accelerometer and a pulse counting accelerometer?

1. The output of the former is in digital form, while that of the later is in analog form
2. The output of the former is in analog form, while that of the latter is in digital form
3. Both outputs are in analog form
4. Both outputs are in digital form

2-64. The earth and a gyroscope both have which of the following operational characteristics?

1. Unreliable stability
2. Varying rotational velocities
3. Limited rotational freedom alignment for their spin axis
4. Magnetic lines of force

2-65. What name is given to the supporting rings of a gyroscope?

1. Gimbals
2. Supports
3. Structures
4. Spatial platforms

2-66. Refer to figure 4-6. A simple gyroscope rotor has what number of degrees of freedom?

1. One
2. Two
3. Three
4. Four

2-67. Refer to figure 4-5. What number of degrees of freedom does this gyroscope possess?

1. One
2. Two
3. Three
4. Four

2-68. If the supporting frame of a free gyro is tilted 90° to the left, the rotor's reaction will be to

1. move 90° upward
2. tilt to the left
3. tilt to the right
4. remain fixed in direction

2-69. Which of the following actions is necessary to use a gyro as a detecting device for solving aircraft armament control problems?

1. Ensure it has enough gimbals
2. Locate it properly in the aircraft
3. Adapt it with some type of pickoff device
4. Select the proper gyro

2-70. At what degree of operation does gimbal lock occur?

1. 30°
2. 60°
3. 90°
4. 180°

2-71. A device used for detecting the angular rate of change of position of an object is known as a/an

1. accelerometer
2. gimbal
3. free gyro
4. rate gyro

Assignment 3

Weapon Control Fundamentals and the Bombing Problem

Text: Pages 5-1 through 6-6

Learning Objective: Recognize the characteristics and definitions relating to weapons control theory. Solve ballistic problems.

3-1. Lead angle can be defined as the angle between

1. the elevation line of the weapon and the horizontal at that point
2. the centerline of the weapon platform and the centerline of the weapon
3. lines extending from the weapon to the target and from the centerline of the weapon
4. a line extending from the centerline of the target and from the centerline of the weapon

3-2. Which of the following factors has the most effect on interior ballistics?

1. Projectile
2. Propellant
3. Primer
4. Rifling

3-3. Actual ballistic trajectory of a projectile may be defined as the curve the projectile follows during

1. burn time
2. the acceleration period
3. free flight
4. the deceleration period

3-4. When does the force of gravity begin acting upon a projectile?

1. The instant it reaches the highest point of its trajectory
2. In the first second of its fall from the highest point of its trajectory
3. In the last second of its rise to the highest point of its trajectory
4. The instant it leaves the muzzle

3-5. If a projectile is fired horizontally from an aircraft in level flight, what total number of feet will the projectile drop in 6 seconds due to gravity?

1. 556
2. 566
3. 576
4. 586

3-6. The velocity of a body falling through the atmosphere increases until

1. its deceleration due to friction equals its acceleration due to gravity
2. it strikes the ground
3. it passes the speed of sound
4. gravity ceases to act upon it

3-7. The path followed by a projectile in its transition from horizontal to vertical flight is determined by air density. Which of the following factors does NOT affect air density?

1. Altitude
2. Relative humidity
3. Atmospheric pressure and temperature
4. Relative wind

● In answering questions 3-8 and 3-9, refer to figure 5-3.

3-8. If the relative air density is 0.5, a projectile will fall 1,2000 yards in what number of seconds?

1. 1.04
2. 1.3
3. 1.4
4. 1.5

3-9. If the relative air density is 0.75, the time it takes for a projectile to fall 800 yards is

1. 1.8 seconds
2. 1.4 seconds
3. 0.9 second
4. 0.4 second

3-10. When using long range aviation fire control equipment, air density must be measured continuously in order to change the lead angle to compensate for

1. changes in projectile flight time
2. wind effect on a slowed projectile
3. gyroscopic action of the projectile
4. changes in muzzle velocity

3-11. If ammunition with a muzzle velocity of 2,600 feet per second is fired from an aircraft traveling at a speed of 300 feet per second, what is the difference between the velocity of a bullet fired dead ahead and of one fired dead astern?

1. 0 feet per second
2. 300 feet per second
3. 600 feet per second
4. 900 feet per second

3-12. An aircraft's indicated airspeed is converted to true airspeed by a comparison of

1. Pitot and static pressures, temperature not being considered
2. static pressure and temperature
3. accurately observed ground check points
4. static pressure with temperature-corrected Pitot pressure

3-13. What is the major cause of projectile drift?

1. The gyroscopic action of the projectile
2. The lateral gravitational effect on the projectile
3. The action of air adhering to the projectile
4. The cushioning effect of air on the projectile

3-14. Which of the following factors must be considered for determining a projectile's air-to-ground trajectory, but NOT its air-to-air trajectory?

1. Range
2. Atmospheric wind
3. Air density
4. Flight time

Learning Objective: Recognize the characteristics of the ballistic bombing problem.

3-15. When a bomb is released, its initial velocity is equal to the

1. difference between the aircraft's true airspeed and groundspeed
2. true airspeed of the aircraft plus the force of gravity
3. true airspeed of the aircraft
4. indicated airspeed of the aircraft

3-16. A bomb is released from an aircraft flying a straight and level course. If atmospheric friction did not exist, where would the bomb strike the ground?

1. On a line directly ahead of the aircraft
2. Halfway between the point of release and the aircraft's position
3. Directly beneath the point of release
4. Directly beneath the aircraft

3-17. The horizontal distance a bomb moves forward from the place of release until impact describes which of the following terms?

1. Drift
2. Range
3. Trail
4. Trajectory

3-18. What force increases a bomb's time of fall?

1. Force of gravity
2. Air resistance in the horizontal direction
3. Air resistance in the vertical direction
4. Force of impact

3-19. Trail of a bomb is caused by

1. gravity
2. headwind
3. air resistance in the vertical plane
4. air resistance in the horizontal plane

3-20. What three factors determine the amount of trail?

1. Airspeed, gravity, and bomb characteristics
2. Altitude, airspeed, and gravity
3. Altitude, gravity, and bomb characteristics
4. Altitude, airspeed, and bomb characteristics

3-21. Which of the following factors does NOT affect the amount of trail?

1. Temperature
2. Wind
3. Altitude
4. Airspeed

3-22. If an aircraft is traveling at a true airspeed of 400 knots with a tailwind of 50 knots, what is the closing speed on a stationary target?

1. 350 knots
2. 400 knots
3. 450 knots
4. 500 knots

3-23. Crosstrail is caused by the drift angle and the natural trail of the bomb.

Learning Objective: Identify the ballistic features of rockets.

3-24. Which of the following is an effect of a crosswind on a rocket which is fired from an aircraft at a surface target?

1. It deflects the rocket at an oblique angle when the plane is in a shallow dive
2. It deflects the rocket to an impact point determined by the square of full wind velocity times the rocket's velocity
3. The effects of the crosswind are too small to consider due to the rocket's short flight time
4. It deflects the rocket to an impact point determined by full wind velocity times the rocket's time of flight

3-25. A projectile is fired in a vacuum. The point at which the vertical velocity is zero is also the point when which of the following events occurs?

1. The target is located
2. Maximum horizontal velocity is achieved
3. Maximum altitude is achieved
4. Gravity no longer acts on the projectile

3-26. If a projectile were fired in a vacuum, the maximum horizontal range would be obtained with a gun elevation of

1. 45 degrees
2. 40 degrees
3. 35 degrees
4. 25 degrees

Questions 3-27 and 3-28 refer to the firing of a rocket from an aircraft.

3-27. The angle between the rocket's launcher line and the aircraft's armament datum line determines the rocket's angle of

1. attack
2. drift
3. lead
4. departure

3-28. What aircraft maneuver minimizes the effect of gravity on the rocket's trajectory?

1. Left roll
2. Right yaw
3. Pitch down
4. Pitch up

3-29. The trajectory of a rocket is more curved than the trajectory of a bullet due to which of the following factors?

1. Lower initial velocity and greater spin
2. Higher initial velocity and longer flight time
3. Higher initial velocity causing a greater angle of departure
4. Longer time of flight and the effects of its fins causing jet forces downward

3-30. A bullet and rocket are similar because they both have top initial speed when fired and neither exerts any recoil.

3-31. Insertion of ballistic information into weapons systems can be accomplished by which of the following means?

1. By use of different plug-in units
2. By the pickup of information recorded in the memory drum of a digital computer
3. By manual insertion of information into the system through a keyboard
4. Each of the above

Learning Objective: Recognize factors relating to solving a trajectory problem.

3-32. The kinematic lead angle is the angle formed between the line of sight to a target aircraft and which of the following attacking aircraft references?

1. Datum line
2. Gun line
3. Yaw axis
4. Pitch axis

3-33. Mil measurement is used for accurate computation of the

1. kinematic lead angle
2. ballistic lead angle
3. visual lead angle
4. total lead angle

3-34. With a lateral lead of 8 mils for a target range of 2,000 yards, what is the difference at the target between the sight line and the gun bore line?

1. 16 yards
2. 24 yards
3. 32 yards
4. 48 yards

3-35. In order to fly a pursuit course, a fighter aircraft must fly a curved path which depends upon the relative target speed and range, the angle of attack, and which of the following factors?

1. The altitude of the target
2. The type of weapon to be used
3. The angle of approach to the target
4. The size of the target

3-36. A fighter pilot would most likely fly a collision course under which of the following conditions?

1. A single salvo is to be fired
2. Constant firing is to be employed
3. The effective firing point cannot be determined
4. Weapons are within range of the target and are bearing on it for several seconds

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Learning Objective: Recognize factors relating to velocity problems. Solve velocity problems.

3-37. Since speed relates to measurement without regard to direction, it is what type of quantity?

1. Vector
2. Angular
3. Relative
4. Scalar

3-38. Magnitude of velocity is determined by

1. dividing distance by time
2. dividing time by distance
3. multiplying distance by time
4. multiplying rate by speed

3-39. An attacking aircraft is headed in a northerly direction at a speed of 1,100 knots toward a target headed in the same direction but traveling at a speed of 900 knots. What is the relative velocity between the two aircraft?

1. 200 knots opening
2. 200 knots closing
3. 2,000 knots closing
4. 2,000 knots opening

3-40. An object is dropped from the roof of a building and its time of fall to the earth is 2 seconds. If air resistance is ignored, what is the velocity of the object at the instant it strikes the ground?

1. 32 feet per second
2. 64 feet per second
3. 320 feet per second
4. 640 feet per second

3-41. Referring to angular velocity, what is the maximum number of radians in one revolution?

1. 3π
2. $2\pi/60$
3. $2\pi(60)$
4. 2π

3-42. An object that is tied to the end of a string is being whirled. The pull on the string toward the center of rotation is known as

1. centrifugal force
2. radial acceleration
3. angular acceleration
4. centripetal force

3-43. If a body is moving at a constant speed along a circular path, its velocity is constantly undergoing change because the

1. body's speed along the radius is increasing
2. velocity's direction is changing
3. angular velocity is changing
4. body's speed along the path is decreasing

3-44. Assume that an aircraft is flying in a circle with a given radius and at a given velocity. If the velocity of the aircraft were doubled, what, if anything, would happen to the centrifugal force on the aircraft?

1. It would be two times greater
2. It would be sixteen times greater
3. It would be four times greater
4. Nothing

3-45. If a pilot weighing 200 pounds is pulling an aircraft out of a dive, and the reading on the accelerometer is 11 g's, what force is acting on the pilot due to acceleration?

1. 2,200 pounds
2. 4,400 pounds
3. 9,900 pounds
4. 24,200 pounds

Learning Objective: Recognize factors relating to fire control problems.

3-46. Refer to figure 5-18. The angle which is measured from the longitudinal axis of a fighter aircraft to the gun-target line is known as

1. the angle to the target
2. the angle difference between targets
3. angle-off of the target
4. angle-on of the target

3-47. The path flown by a target aircraft, as viewed from the attacking aircraft, is known as the

1. aircourse
2. pursuit course
3. collision course
4. relative course

3-48. Which of the following is the most important course to be determined in solving an air-to-air fire control problem?

1. The collision course
2. The relative course
3. The air course
4. The pursuit course

3-49. Preparatory to firing a stationary gun at a stationary target, the angle at which the gun must be aimed will be determined by the expected effects of gravity and the

1. wind
2. kinematic lead
3. parabolic trajectory lead
4. projectile's time of flight

3-50. When a gun is aimed at a point ahead of a moving target in order to compensate for the relative motion of the target with respect to the projectile, the lead is known as a

1. projectile lead
2. ballistic lead
3. gravity lead
4. kinematic lead

3-51. Assuming an aircraft is strafing a fixed target, what type of lead is required?

1. Positive
2. Negative
3. Ballistic
4. Gravity

3-52. For practical purposes, the lead angle of a projectile at any instant of time is equal to the

1. target's range rate times the projectile's flight time
2. angular velocity of the projectile times the distance to the target
3. change in velocity due to air drag times the projectile's flight time
4. angular velocity of the target times the projectile's flight time

3-53. One factor that determines the relative velocity of a target is angular rate and another one is

1. range rate
2. lead rate
3. deflection rate
4. relative rate

3-54. What are the components into which the angular rate of a target aircraft is divided?

1. Azimuth, angular velocity, and range
2. Range velocity and elevation angular velocity
3. Angular velocities of azimuth and elevation
4. Azimuth rate and range rate

3-55. In radar tracking equipment, what are the maximum number of gyroscopes used to measure angular velocity?

1. Five
2. Two
3. Three
4. Four

Learning Objective: Recognize characteristics of ballistic and kinematic lead angles.

3-56. Refer to figure 5-21. The flight of the projectile at the time of firing is affected by the

1. turning motion of the firing aircraft
2. turning motion of the target aircraft
3. direction and speed of the target aircraft
4. direction and speed of the firing aircraft

3-57. The size of a kinematic lead angle is generally larger than the ballistic lead angle.

Learning Objective: Recognize functions and components of weapons systems.

3-58. A weapons system contains units capable of accomplishing which of the following actions?

1. Controlling or directing a weapon or delivery unit
2. Delivering or initiating delivery of a weapon to the target
3. Detecting, locating, and identifying targets
4. Each of the above

3-59. Which of the following types of devices is usually used to control weapons systems?

1. Gyroscopic
2. Hydraulic
3. Manual
4. Pneumatic

Learning Objective: Recognize definitions and characteristics relating to the bombing problem. Compute trail.

3-60. Refer to figure 6-1. If a bomb were dropped while level bombing in a vacuum, at the exact time of impact the bombing aircraft would be located at which of the following points?

1. Forward of the point of impact
2. Aft of the point of impact, regardless of the weight of the bomb
3. Directly above the point of impact
4. Aft of the point of impact, depending upon the weight of the bomb

3-61. In a horizontal bombing problem, of what does the range angle consist?

1. Horizontal and the line of sight to the target
2. Vertical and the line of sight to the target
3. Vertical and the line of flight
4. Line of flight and wind direction

3-62. What are the three variable factors required to compute range angle?

1. Range, altitude, and gravity
2. Aircraft velocity, range, and temperature
3. Aircraft velocity, altitude, and gravity
4. Temperature, gravity, and aircraft velocity

3-63. Which of the following factors in a bombing problem is a constant?

1. Ballistic coefficient of the bomb type
2. Bomb range to the target
3. Range of the bomb if released in a vacuum
4. Time of fall of the bomb

3-64. The term that describes the distance that the bomb lags behind the aircraft at the instant of bomb impact is known as the

1. trail
2. trajectory
3. depression
4. toss

3-65. Refer to figure 6-2. If a table lists the trail angle for a bomb as 30 mils and the bomb is dropped from 15,000 feet, what is the amount of trail?

1. 450 feet
2. 900 feet
3. 1,200 feet
4. 1,600 feet

● In answering questions 3-66 and 3-67, refer to figure 6-7.

3-66. The angle between the course an aircraft is steering and its course over the ground is known as the

1. corrected angle of heading
2. angle of drift
3. trail angle
4. steering angle

3-67. Which of the following is a characteristic of trail?

1. It is dependent upon wind velocity
2. It is determined by the altitude/air density ratio
3. It is independent of the wind
4. It is offset from the aircraft's longitudinal axis by an amount determined by angle θ

3-68. Altitude above the target, time of flight of the bomb, and the closing speed are used to compute the

1. drift angle of the attacking aircraft
2. correct range of the target
3. cross trail of the bomb
4. trajectory of a bomb in a vacuum

3-69. Compared with other variables, trail is negligible in computations for bombing at altitudes between

1. 500 and 1,000 feet
2. 1,000 and 2,000 feet
3. 2,000 and 3,500 feet
4. 3,500 and 5,000 feet

3-70. Refer to figure 6-5. In dive bombing, the procedure the pilot follows is to aim the aircraft at

1. the target and pull up just before the release point is reached
2. a point in front of the target, and pull up and release the bomb at a point after pullup
3. a point beyond the target until the release point is reached
4. the target until the release point is reached

3-71. Which of the following is an advantage of loft bombing compared to other types of low-level bombing?

1. No preflight planning is required
2. The bomb may be released at any time during the approach run
3. The aircraft is farther away from the target at bomb impact
4. It is more effective at any altitude

A. Dive Bombing
B. Toss bombing
C. Loft bombing
D. Over-the-shoulder bombing

Figure 3A.

Refer to figure 3A in answering questions 3-72 through 3-75.

3-72. In what bombing method is the bomb released when the product of pull-up time, acceleration, and release angle reach a preset value?

1. A
2. B
3. C
4. D

3-73. Determining the proper point at which to aim the aircraft is the biggest problem in what bombing method?

1. A
2. B
3. C
4. D

3-74. The target and the identification point are the same in what bombing method?

1. A
2. B
3. C
4. D

3-75. In what bombing method is the pilot concerned only with aiming the aircraft and controlling its speed?

1. A
2. B
3. C
4. D

Assignment 4

Radar Circuits

Text: Pages 7-1 through 7-45

Learning Objective: Recognize the functions of the synchronizer and identify the various waveforms produced in a radar system.

4-1. What is the basic function of the radar timer?

1. To produce range markers
2. To sychronize the sweep voltage or current for the indicator with the transmitter pulse
3. To synchronize the current and sweep voltage to produce gating circuits
4. To produce sweep pulses

4-2. In an externally synchronized system, the timing trigger pulses are obtained from

1. the transmitter
2. a master oscillator, usually configured internally
3. a master oscillator, usually external to the transmitter
4. the receiver

4-3. The basic timing circuit must meet what total number of requirements?

1. One
2. Two
3. Three
4. Four

4-4. Refer to figure 7-2. What determines the repetition rate of the timing pulses shown?

1. The frequency of the astable multivibrator
2. the frequency of the single-swing blocking oscillator
3. The frequency of the sine-wave oscillator
4. All of the above

4-5. What is the main disadvantage of a sine-wave timer?

1. Cost
2. Size
3. The large number of pulse-shaping circuits
4. The small number of pulse-shaping circuits

4-6. What is the main advantage of the single-swing blocking oscillator?

1. It generates two signals, 180 degrees out of phase
2. It generates sharp pulses directly
3. It generates positive triggers
4. It generates negative triggers

4-7. An intercept radar operating in the track mode must provide range data that is accurate to within which of the following measurements?

1. Inches
2. Feet
3. Yards
4. Miles

4-8. Refer to figure 7-3. The output of the thyratron is used for which of the following purpose(s)?

1. To trigger the radar modulator
2. To trigger the B-scope sweep circuits
3. To trigger the transmitter pulse
4. Each of the above

4-9. Refer to figure 7-4. The output of the ringing oscillator is what type of waveform?

1. Positive going
2. Sinusoidal
3. Square wave
4. Negative going

4-10. In B-scope and PPI-scope applications, the output of the range marker generator is applied to the

1. transmitted pulse
2. deflection plates
3. video mixer
4. CRT directly

4-11. Refer to figure 7-5(A). What is the purpose of potentiometer R3?

1. To control the output frequency of the circuit
2. To position the range step along the indicator time base
3. To control the bias of Q1
4. To limit the output voltage of the circuit

Learning Objective: Recognize the functions of the radar transmitter and its associated circuitry.

4-12. What is the purpose of the transmitter?

1. To develop high-power high-frequency pulses of RF energy which are radiated into space by the antennae
2. To develop low-power high-frequency pulses of RF energy which are radiated into space by the antennae
3. To develop high-power low-frequency pulses which are radiated into space by the antennae
4. To develop low-power low-frequency pulses which are radiated into space by the antennae

4-13. What unit in the radar system controls the radar pulse width by means of a rectangular dc pulse of the required duration and amplitude?

1. The modulator
2. The synchronizer
3. The transmitter
4. The receiver

4-14. In a radar system, the timing circuit must be triggered the instant the leading edge of the transmitted RF pulse leaves the transmitter in order that which of the following determinations can be made?

1. Maximum target range
2. Minimum target range
3. Good target resolution
4. Accurate target range

4-15. what total number of types of modulators are used in radar systems?

1. One
2. Two
3. Three
4. Four

4-16. A modulator has what total number of basic components?

1. One
2. Two
3. Three
4. Four

4-17. Refer to figure 7-7. With the modulator switch open, the storage element is affected in which of the following ways?

1. It stores no energy
2. It produces maximum power
3. It stores a large amount of power
4. It discharges through the transmitter

4-18. Which of the following is a type of storage element used in a modulator?

1. Capacitor
2. Artificial transmission line
3. Pulse-forming network
4. Each of the above

● Refer to figure 7-9(A) in answering questions 4-19 and 4-20.

4-19. The charge and discharge of C1 is controlled by what component in the circuit?

1. Q1
2. The dc power supply
3. CR1
4. The RF oscillator

4-20. The modulator pulse width is dependent upon what factor?

1. The frequency of the RF oscillator
2. The width of the trigger pulse applied to the base of Q1
3. The size of the charging diode
4. The size of the storage capacitor

4-21. Refer to figure 7-9(B). What component controls the pulse repetition rate of this circuit?

1. DC power supply
2. Charging impedance Z1
3. Modulator switch
4. Pulse transformer

4-22. Pulse-forming networks are often insulated by the use of

1. glass
2. fiberglass
3. oil
4. a heat sink

4-23. A switching device must perform what total number of functions?

1. One
2. Two
3. Three
4. Four

4-24. Modulator switch functions are best met by which of the following devices?

1. Magnetron
2. Thyratron
3. Artificial transmission line
4. Pulse-forming network

4-25. Refer to figure 7-11(A). If the charging resistor is replaced by an inductor, the charging circuit becomes what type of circuit?

1. Parallel-resonant
2. Series-resonant
3. Capacitive
4. Reactive

4-26. The addition of a diode to the resonant charging circuit permits the storage element to charge to what voltage as compared to the applied voltage?

1. One-half the applied voltage
2. Twice the applied voltage
3. The same as the applied voltage
4. Four times the applied voltage

Learning Objective: Recognize the functions of the receiver and its various parts.

4-27. Refer to figure 7-12(B). In a radar receiver microwave mixer, the crystals are located at what distance from their respective short-circuited waveguide end?

1. One wavelength
2. Two wavelengths
3. One-half wavelength
4. One-quarter wavelength

4-28. Refer to figure 7-15. As used in this circuit, CR1 functions as a

1. resistor
2. capacitor
3. transistor
4. varactor

4-29. Refer to figure 7-17. Q1 and Q2 perform what function in the circuit?

1. A cathode follower
2. A mixer
3. A low-gain cascade amplifier
4. A high-gain cascade amplifier

4-30. In a radar receiver, the AFC circuits tune the local oscillator to the correct operating frequency for what reason?

1. So the receiver is able to process the received signal
2. So the receiver is able to pass the received signal
3. So the local oscillator is tuned during received time
4. So the local oscillator is not tuned during transmit time

● In answering questions 4-31 and 4-32, refer to figure 7-27.

4-31. The comparator output goes through either CR1 and CR2 or through CR3 and R1 depending upon what factor?

1. The state of the video error signal
2. The state of the search signal
3. The polarity of the comparator output
4. The output of the summing amplifier

4-32. What is the IF bandpass of the circuit?

1. ± 5 MHz
2. ± 10 MHz
3. ± 30 MHz
4. ± 60 MHz

4-33. What number of paths or loops make up the loop-control mode of AFC circuits?

1. One
2. Two
3. Three
4. Four

4-34. In an AFC circuit, what is the bandpass of the fast-loop operation?

1. ± 5 MHz
2. ± 10 MHz
3. ± 30 MHz
4. ± 60 MHz

4-35. What is the simplest type of gain control used in radar IF amplifiers?

1. Manual
2. AFC
3. STC
4. IAGC

4-36. In radar receivers, what approximate variation in gain can be achieved by the control of a single stage?

1. 10 dB
2. 20 dB
3. 30 dB
4. 40 dB

4-37. The type of gain control used in a radar receiver depends upon which of the following factors?

1. The type of circuits being used
2. The speed of AGC response desired
3. The type of AGC response desired
4. Each of the above

4-38. The IAGC instantaneously controls the gain of the IF amplifier as the return signal changes in amplitude. What limits the range of the IAGC?

1. The type of AFC used
2. The type of STC used
3. The number of IF stages in which gain is controlled
4. The amplitude of the input signal

4-39. Which of the following is the result when a combination of STC and IAGC is used.

1. Better overall performance
2. Weak long-range target returns
3. Weak short-range target returns
4. A radar that cannot be jammed

4-40. What is the purpose of gated AGC circuits in radar amplifiers?

1. To gate unwanted signals through for presentation
2. To compensate for IAGC
3. To gate any signal through, no matter how large
4. To use in antijamming circuits

4-41. Refer to figure 7-25(A). What is the amount of negative feedback from 50 KHz to 5 MHz in this circuit?

1. 10 dB
2. 20 dB
3. 34 dB
4. 44 dB

Learning Objective: Recognize the different types of radar scopes, the basic method in which they are generated and identify the type of information that each display can present.

4-42. Which of the following types of scopes is NOT Used in modern weapons systems radar?

1. A-scope
2. B-scope
3. C-scope
4. PPI-scope

4-43. The one-shot multivibrator in an A-scope generates which of the following types of gate pulses?

1. A positive gate pulse that is fed to the range marker generator
2. A positive gate pulse that is fed to the range sweep generator
3. A negative gate pulse that is fed to the control grid of the CRT
4. A negative gate pulse that is fed to the range sweep generator

4-44. In the A-scope sweep presentation, what signal intensifies the CRT during sweep time?

1. The negative gate applied to the control grid of the CRT
2. The positive gate applied to the control grid of the CRT
3. The positive gate applied to the horizontal-deflection plates
4. The negative gate applied to the horizontal-deflection plates

4-45. In a B-scan display, which of the following variables are possible?

1. Range
2. Azimuth
3. Intelligence
4. Each of the above

4-46. In a C-scope presentation, what is represented by the vertical axis?

1. Range only
2. Azimuth only
3. Range and azimuth
4. Elevation

4-47. In a PPI-scope presentation, what is represented by the distance along the sweep line?

1. Target range only
2. Target azimuth only
3. Target range and azimuth
4. Target elevation

4-48. Normally, what information is shown on the center of a PPI display?

1. Range of the target
2. Range of the radar
3. Location of the target
4. Location of the radar

4-49. The E-scan presentation displays which of the following information?

1. Range and bearing
2. Azimuth and bearing
3. Range and height
4. Azimuth and height

4-50. Refer to figure 7-35. The size of the range circle gives what target information?

1. Size
2. Range
3. Bearing
4. Elevation

4-51. To produce a circle on a CRT, what signals must be applied?

1. Two sine waves 180 degrees out of phase
2. Two square waves 180 degrees of phase
3. Two sine waves 90 degrees out of phase
4. Two square waves 90 degrees out of phase

Learning Objective: Recognize the purpose, uses, advantages, and limitations of microelectronics.

4-52. The trend toward miniaturization began with the use and development of what device?

1. Vacuum tubes
2. FETs
3. Transformers
4. Transistors

4-53. Which of the following is NOT an advantage of the thin film process of fabricating complete circuits?

1. The decrease in the number of components
2. The ease in disconnecting the components of the circuit from each other
3. High density of the components
4. The replacement of soldered and mechanical connections by the intimate ones formed at the time material is deposited

Assignment 5

Weapons Control Radar System and Principles of Navigation

Text: Pages 8-1 through 9-29

Learning Objective: Recognize the operating modes and submodes of the 11D13A trainer.

5-1. What are the modes of operation for the 11D13A trainer?

1. Search, track, and bomb director
2. Search, fire control, and bomb director
3. Track, fire control, and search
4. Fire control, bomb director, and track

5-2. The automatic time in (time delay) is used for what purpose in most radar sets?

1. To prevent application of power to the high voltage section of a radar prior to proper warmup time
2. To prevent power from being applied to the filament voltages
3. To prevent the radar from transmitting until airborne
4. To prevent personnel from being injured while working on the radar

5-3. In the operation of a radar set, the time period for acquisition begins when

1. lockon is obtained
2. power is applied
3. the operator switches control from automatic search to manual search
4. the operator places the acquisition symbol over the target

5-4. During the search mode of operation, which of the following functions is NOT available?

1. Selectable range marks
2. Horizon antenna scan
3. Operating range between 0 and 12,000 yards
4. Operable B-scope

5-5. What is the total number of submodes available in the fire control mode?

1. One
2. Two
3. Five
4. Four

5-6. In the fire control mode, operation is limited to what minimum range?

1. 0 yards
2. 10,000 yards
3. 3,500 yards
4. 40,000 yards

5-7. Which of the following is NOT a feature of the bomb director mode?

1. The PPI display is available
2. The bomb director mode operating ranges are the same as search mode ranges
3. The operator controls range markers
4. The operator controls azimuth markers

Learning Objective: Recognize 11D13A system controls and their effects.

5-8. The basic controls are grouped into what total number of major categories?

1. One
2. Two
3. Five
4. Four

5-9. The standby position of the power switch of the 11D13A applies power to what component(s)?

1. Filaments
2. Keep-alive voltage of the TR tubes
3. Both 1 and 2 above
4. Transmitter

5-10. The mode switch selects one of the basic submodes of system operation.

5-11. Which of the following radar installation controls allows the operator to select manual search?

1. Antenna
2. Mode
3. Receiver gain
4. Power switch

Learning Objective: Recognize the indicator display features of the three basic modes of operation.

5-12. In the basic search mode, what type of display is presented?

1. B-scope
2. Depressed-center PPI
3. PPI
4. A-scope

5-13. Refer to figure 8-3. When you are using the automatic search mode, what feature on the B-scope can be used to mark an area of target return?

1. Range sweep
2. Acquisition symbol
3. Displayed target
4. Horizon line

5-14. The appearance of which of the following symbols constitutes a major display difference between the automatic and manual search modes?

1. Range sweep
2. Target
3. Horizon line
4. Acquisition symbol

5-15. Refer to figure 8-5. Which of the following indications does NOT appear when lockon occurs?

1. The lockon light comes on
2. The steering dot appears
3. The range circle disappears
4. The acquisition symbol is replaced with a range strobe

5-16. When you are using the fire control (automatic track) mode, which of the following conditions will NOT cause the system to break lockon?

1. The target exceeds the maximum range of the radar
2. The opening rate of the target is greater than 200 knots
3. The target exceeds the azimuth or elevation limits of the system
4. The closing rate of the target is less than 700 knots

5-17. Which of the following events occurs in the fire control (breakaway) mode?

1. The breakaway symbol appears
2. The steering dot is removed
3. The range notch is removed
4. The range circle appears

5-18. Refer to figure 8-7. When the bomb director mode of operation is selected, information is displayed on which of the following indicators?

1. E-scope
2. A-scope
3. C-scope
4. Depressed-center PPI

Learning Objective: Identify the basic components of the 11D13A and their functions.

5-19. Refer to figure 8-8. What is the basic frequency of the 11D13A?

1. 1 MHz
2. 100 kHz
3. 10 MHz
4. 1 kHz

5-20. To ensure proper range on the sweep, the range marks circuit must be triggered at which of the following times?

1. Upon receipt of the first signal
2. The moment the transmitter is fired
3. Two microseconds after receipt of the first signal
4. Two microseconds after the transmitter is fired

5-21. Refer to table 8-1. Which of the following signals can be either 37 or 74 microseconds in width?

1. Sweep gate
2. Delayed trigger
3. Doppler gate
4. Range marks

5-22. Which of the following components compose the transmitter?

1. Syncronizer, modulator, and magnetron
2. Syncronizer, modulator, and trigger generator
3. Trigger generator, magnetron, and power supplies only
4. Modulator, magnetron, power supplies, and trigger generator

5-23. Refer to figure 8-9. The trigger from the syncronizer is applied to what part of the transmitter?

1. Modulator
2. Modulator power supply
3. Trigger generator
4. Magnetron

5-24. What is the approximate voltage necessary to operate the modulator and magnetron?

1. 100 V
2. 500 V
3. 5,000 V
4. 10,000 V

5-25. What effect, if any, does removing the cover have upon the transmitter?

1. The input triggers are removed
2. The power is removed
3. The cooling air is removed from the transmitter
4. None

5-26. The purpose of the Doppler signal produced in the receiver is to provide a/an

1. video signal indicating target position
2. video signal indicating target speed
3. audio signal indicating target position
4. audio signal indicating target speed

● Refer to figure 8-10 in answering questions 5-27 through 5-29.

5-27. What is the bandwidth of the stagger-tuned IF amplifiers?

1. 1 MHz
2. 10 MHz
3. 100 MHz
4. 4 MHz

5-28. What is the output of the detector?

1. A positive, 1-microsecond video pulse
2. A negative, 1-microsecond audio pulse
3. A positive, 1-microsecond audio pulse
4. A negative, 1-microsecond video pulse

5-29. What component controls the initial operating level of the STC circuit?

1. The pulse amplifier V204
2. The gain control selector
3. The manual gain control
4. The delayed gate from the syncronizer

5-30. The receiver IF circuits are tuned to what frequency?

1. 30 kHz
2. 30 MHz
3. 10 kHz
4. 10 MHz

5-31. Which of the following is NOT a component of the B-scope?

1. An A-gun
2. A B-gun
3. Two independent deflection systems
4. One shared deflection system

5-32. The time-sharing gates of the A-gun determine the sequence of the display. Which of the following is the correct A-gun time-shared display sequence?

1. Breakaway symbol, horizon line, dot, clamp, and range circle
2. Breakaway symbol, range circle, horizon line, clamp, and dot
3. Range circle, breakaway symbol, clamp, dot, and horizon line
4. Range circle, breakaway symbol, horizon line, dot, and clamp

5-33. The range circle is formed by applying what two signals to the horizontal and vertical deflection plates?

1. Two sine waves, phased 90 degrees apart
2. Two sine waves, phased 30 degrees apart
3. Two square waves, phased 90 degrees apart
4. Two square waves, phased 30 degrees apart

5-34. Which, if any, of the following signals are generated by the B-gun?

1. Range circle and target video
2. Range sweep line, acquisition symbol, and dot
3. Range sweep line, acquisition symbol, and target video
4. None of the above

5-35. The range sweep line is generated by which of the following signals?

1. A sawtooth of voltage and an azimuth voltage
2. A sawtooth of voltage and a range voltage
3. A sine wave and a range voltage
4. A square wave and a range voltage

5-36. With the scan control switch in PPI, what is the scan angle of the radar?

1. 30 degrees
2. 60 degrees
3. 90 degrees
4. 360 degrees

5-37. What is/are the total number of antennas in the 11D13A?

1. One
2. Two
3. Three
4. Four

5-38. Refer to figure 8-18. Which of the following components controls the size of the range marks?

1. R14104
2. R14102
3. R14108
4. R14115

5-39. Refer to figure 8-19. What is the output of A1 when it is triggered?

1. A 2,000-microsecond negative gate
2. A 2,000-microsecond positive gate
3. A 4,000-microsecond negative gate
4. A 4,000-microsecond positive gate

5-40. Refer to figure 8-20. What time delay, in microseconds, does DL1901 add to the circuit?

1. 1
2. 2
3. .5
4. .8

Learning Objective: Recognize the methods and terminology of navigation.

5-41. When a navigator measures speed and heading and uses these values to compute position changes from an initial starting point, what method of navigation is being used?

1. Electronically aided
2. Dead reckoning
3. Celestial
4. Visual

5-42. When you navigate by dead reckoning, the vehicle's speed is resolved using which of the following velocities?

1. North and south
2. North and west
3. North and east
4. South and east

5-43. In the following formula, x is equal to what factor?

$x = \int V \quad dt = \int a \, dt \, dt$

1. Distance
2. Velocity
3. Time
4. Speed

5-44. Refer to figure 9-2. If "a" is zero (the ball is at the center of the disc), the constant disc rotation will cause the output shaft to

1. remain stationary
2. accelerate negatively
3. remain unbalanced
4. accelerate positively

5-45. Which of the following is NOT a component of the gyro shown in figure 9-3?

1. W gyro torquer
2. X gyro torquer
3. Platform azimuth torquer
4. Platform pitch torquer

5-46. Which of the following is NOT a reason for using Schuler tuning?

1. It maintains the platform perpendicular to the earth's gravity
2. It reduces long-term errors
3. It increases long-term errors

5-47. What total number of minutes constitutes the period of a Schuler loop?

1. 21.1
2. 42.2
3. 63.3
4. 84.4

5-48. In a Schuler loop, the gyro in the north loop senses the vehicle's angular movement around the

1. north-south axis
2. east-west axis
3. north-east axis
4. east-south axis

- Refer to figure 9-7 in answering questions 5-49 and 5-50.

5-49. Which of the following definitions refers to the term V_{CO}?

1. True acceleration
2. Computed initial velocity
3. Computed position
4. Computed angular rate of platform with relation to horizontal

5-50. Which of the following definitions refers to the term P_C?

1. Computed initial velocity
2. Computed velocity
3. Computed initial position
4. Computed position

5-51. In inertial navigation, what term is given to the acceleration caused by the earth's rotation?

1. Coriolis
2. Vertical
3. Circular
4. Spherical

5-52. What is the total number of initial conditions that must be set before an inertial system can navigate accurately?

1. One
2. Two
3. Three
4. Four

5-53. What is the cause of accelerometer bias and gyro drift rate errors?

1. The earth's rotation
2. The mechanical imperfections of the components
3. The radius of the earth
4. The nonspherical nature of the earth

A. Aligning

B. Leveling

C. Slaving

D. Gyrocompassing

Figure 5A.

In items 5-54 through 5-56, select from figure 5A the process applicable to the description used as the question.

5-54. Torquing the system's gimbals to a position as defined by an external reference.

1. A
2. B
3. C
4. D

5-55. Moving the platform's sensitive axes to a known azimuth position.

1. A
2. B
3. C
4. D

5-56. Moving the stable platform to such a position that the accelerometers do not sense gravity components.

1. A
2. B
3. C
4. D

5-57. Which of the following is NOT a feature of self initialization?

1. External directional references are used
2. Internal directional references are used
3. The system orients itself by using computations performed on the outputs of its own sensors
4. The system orients itself by using computations performed on the outputs of its gyros and accelerometers

5-58. Which of the following is a characteristic of acceleration leveling?

1. When the platform is level, the accelerometer has an output
2. When the platform is not level, the earth's gravity produces an accelerometer output
3. When the platform is level, the gyro has an output
4. When the platform is not level, the earth's rotation produces an accelerometer output

5-59. Refer to figure 9-12. What is the purpose of the -K amplifier?

1. To torque the accelerometer
2. To amplify the input to the accelerometer
3. To torque the gyro
4. To amplify the physical inputs

5-60. Which of the following is a characteristic of the north gyro when it is located at the North Pole?

1. It senses the entire earth's rotation rate
2. It senses none of the earth's rotation rate
3. It goes into gyrocompassing
4. It comes out of gyrocompassing

5-61. Refer to figure 9-15. What symbol(s) in the figure represent(s) the east gyro?

1. $\Omega_{IE}\cos L$
2. $-\Omega_{N}\sin$
3. Y
4. X

5-62. Refer to figure 9-18. Which of the following conditions must exist to keep the azimuth error to a small value?

1. -K2 gain must be low
2. -K2 gain must be high
3. -K3 gain must be low
4. -K3 gain must be high

5-63. Azimuth transient errors sensed by the gyrocompass loop may peak at a maximum of how many times as large as the initial tilt error?

1. 10
2. 20
3. 30
4. 40

Learning Objective: Recognize operating principles and characteristics of navigational Doppler radar.

5-64. A CW Doppler radar senses velocity by measuring a reflected signal's change in

1. pulsewidth
2. return time
3. amplitude
4. frequency

5-65. Along a straight-line distance between the transmitter and receiver, the amplitude of the Doppler shift is directly proportional to the closing or receding

1. range
2. velocity
3. altitude
4. earth

5-66. Refer to figure 9-19. What aircraft, if any, is flying the fastest?

1. A
2. B
3. C
4. None

5-67. Refer to figure 9-20. Aircraft A is flying faster than aircraft B.

5-68. In the radar navigation set AN/APN-122(V), the two beams are directed symmetrically fore and aft.

5-69. When you are using a dual oblique-beam Doppler system, the direction of drift can be derived from the beam which registers the least frequency shift.

5-70. What indication, if any, will the operator receive indicating that the the Doppler system is operating in the search mode?

1. The memory light illuminates
2. The memory light extinguishes
3. The AGC light illuminates
4. None

5-71. Refer to figure 9-24. Which of the following is a characteristic of the AN/APN-153(V)?

1. It is a two-beam system
2. Servo motors drive the antenna into alignment with the aircraft's ground track
3. Servo motors drive the antenna into alignment with the aircraft's heading
4. It is a continuous-wave system

5-72. Which of the following is NOT a feature of the AN/APN-190(V)?

1. It operates in the GHz frequency range
2. It is a solid state system
3. It is a four-beam-pair system
4. It measures ground speed and drift angle

5-73. The beam pattern of the AN/APN-190(V) is radiated fore and aft along the aircraft's fore-aft axis.

5-74. Switching and beam lobing in the AN/APN-190(V) are caused by

1. duplexer inputs
2. waveguide outputs
3. crystal switches
4. coded signals

5-75. The AN/APN-190(V) is able to compensate for what maximum number of degrees of drift?

1. 30
2. 60
3. 180
4. 360

Assignment 6

Electro-Optical Sights, Electric Power and Ground Cooling Systems, and Television

Text: Pages 10-1 through 12-11

Learning Objective: Recognize the purpose, operating principle, and display characteristics of the AN/AVQ-7(V) Head-Up Display.

6-1. What is the display source of the modern electro-optical sight?

1. Transistor
2. Pixie tube
3. Resistor
4. Cathode-ray tube

6-2. The transparent mirror that displays information to the pilot using the AN/AVQ-7(V) is known as a

1. reflector
2. combiner
3. mirror-reflector
4. windscreen

6-3. Refer to figure 10-3. If the signal data processor were to apply a Y signal to the HUD, it would provide what type symbol on the combiner?

1. Power-on
2. Horizontal
3. Vertical
4. Bright-up

6-4. The precision 15-volt dc power output is used for excitation by which of the following devices?

1. Angle-of-attack transducer
2. Air data computer
3. Doppler radar
4. All the above

6-5. What is the purpose of the busy signal?

1. To allow transfer of data to the display unit
2. To prevent transfer of information to the display unit
3. To decode information
4. To generate a self-test mode

6-6. The input receivers use what form of data transfer?

1. Serial
2. Parallel
3. Serial/parallel

6-7. Data identity signals consist of what total number of bits of data?

1. 1
2. 2
3. 10
4. 20

6-8. Which of the following devices generates the data clock pulse that is applied to the input receivers?

1. Identity register
2. Symbol generator
3. Tactical computer
4. Discrete receivers

6-9. Exactly how many discrete lines are contained in the input receivers?

1. 6
2. 12
3. 18
4. 24

6-10. Within the digital computer, designated letters are used to represent certain phases of digital computer operation. If a number were to appear after the letter, what information would be indicated?

1. The number of steps in the phase of operation
2. The type of operation to be performed
3. The location of the operation to be performed
4. The specific step of the phase in progress

6-11. What is the first program of instruction selected at the start of digital computer operations?

1. Program select
2. Data accumlation
3. DNI
4. Memory on

6-12. In which, if any, of the following modes of operation does the signal generator operate?

1. Line, circle, and ADC
2. Line, dot, circle, and ADC
3. Line, circle, and dot
4. None of the above

6-13. During the sixth and seventh operations of the line mode, what action occurs with respect to the X and Y data?

1. X2 data is shifted
2. Y2 data is shifted
3. The X and Y channel rate registers are shifted by the symbol generator
4. The X and Y channel rate registers are checked for correctness by the BITE circuits

6-14. When the circle mode of operation in the signal generator is being used, the circle is drawn (a) in what direction beginning at (b) what point on the CRT?

1. (a) Clockwise
   (b) bottom
2. (a) Clockwise
   (b) top
3. (a) Counterclockwise
   (b) top
4. (a) Counterclockwise
   (b) bottom

6-15. What is the purpose of the bright-up pulse delay in the circle mode of the signal generator?

1. It compensates for the slow response time of the deflection circuits in the HUD
2. It compensates for the fast response time of the deflection circuits in the HUD
3. It turns off the symbol generator
4. It turns on the symbol generator

6-16. What voltage is applied to the CRT anode of the HUD?

1. 5,000 volts
2. 10,000 volts
3. 15,000 volts
4. 20,000 volts

6-17. Electrical power used for operation of the standby reticle is obtained from

1. the low voltage power supply
2. outside the HUD
3. a battery
4. the high voltage power supply

6-18. Symbols are drawn at what rate on the CRT?

1. 10 times a second
2. 20 times a second
3. 50 times a second
4. 100 times a second

6-19. What controls the symbol brightness of the CRT in the HUD?

1. The X and Y bright-up signal
2. The X and Y amplifiers
3. The control grid circuit of the CRT
4. The cathode bias circuit

6-20. Refer to figure 10-7. An output of OG-1 will give which of the following indications?

1. The system will operate normally
2. There will be an SDP fail indication
3. The CRT will blossom
4. There will be a HUD overheat light

6-21. The input side of the OG-1 is capable of receiving what total number of signals?

1. 6
2. 9
3. 3
4. 12

6-22. Which of the following statements describes the reset function of the HUD unit fail indicator?

1. The indicator is automatically reset when the problem is corrected
2. The indicator must be manually reset after it is activated
3. The indicator cannot be reset until the problem is corrected
4. The indicator must be reset by cycling the master generator switch

6-23. Which of the following ordnance information is NOT ordnance information displayed on the AVA-12?

1. Number of rounds remaining
2. Heading
3. Type of weapon selected
4. Number of weapons ready for launch

6-24. Which of the following is a function of the declutter feature of the AVA-12?

1. It is used to rearrange the symbols on the HUD
2. It is used primarily in the air-to-ground mode of operation
3. It is used to remove preselected unwanted symbols from the display
4. It is used to remove all symbols from the display

6-25. The AVA-12 has what total number of basic modes of operation?

1. 1
2. 2
3. 3
4. 5

Learning Objective: Identify the components of a basic aircraft electrical system and recognize their function in normal and emergency situations.

6-26. Older type aircraft used engine-driven generators to produce what nominal voltage?

1. 12 volts dc
2. 27.7 volts dc
3. 115 volts ac
4. 220 volts ac

6-27. In a modern aircraft, ac power is converted into dc power through the use of what device?

1. Generator
2. Inverter
3. Transformer-rectifier
4. Dynamotor

6-28. What is the basic power source for an electrical system in an aircraft?

1. Generator
2. Ram-air turbine
3. Rectifier
4. Engine

6-29. What device is inserted between the engine and the ac generator in order to provide a constant speed to the generator?

1. A CSD unit
2. A governor
3. A rectifier
4. A dynamotor

6-30. What is the output frequency of an aircraft ac generator?

1. 50 Hz
2. 60 Hz
3. 115 Hz
4. 400 Hz

6-31. When the emergency generator is in operation, which of the following types of equipment will be operable?

1. Essential equipment only
2. All electrical equipment
3. All equipment will work if the emergency generator is operating correctly
4. All equipment will work but at less than normal operation

6-32. Refer to figure 11-1. What is the purpose of CR1 in this circuit?

1. To provide current regulation
2. To act as a voltage divider
3. To act as a full-wave bridge rectifier
4. To act as a filter circuit

6-33. Which of the following publications contains a discussion of transformer-rectifier units for each applicable aircraft?

1. MIM
2. NATOPS
3. TMI
4. RTM

6-34. What device is used to convert low voltage dc to ac?

1. Frequency change
2. Rectifier
3. Amplifier
4. Inverter

6-35. The F-14 has what total number of power sources?

1. 1
2. 2
3. 3
4. 4

6-36. What type of force is used to drive the emergency generator in the F-14 aircraft?

1. Electric
2. Hydraulic
3. Pneumatic
4. Mechanical

6-37. The F-14 electrical system can receive power from which of the following sources?

1. External power only
2. Generator power only
3. External power and generator power

6-38. Which of the following devices will NOT protect the aircraft's electrical system from damage and failure?

1. Fuses
2. Current limiters
3. Relays
4. Circuit breakers

6-39. Which of the following devices are used for control and distribution of power in an electrical system?

1. Relays only
2. Current limiters
3. Fuses
4. Switches and relays

6-40. Which of the following is a cause of fuse failure?

1. Heat
2. Current
3. Voltage
4. Wattage

6-41. If the following fuses were rated the same, which one would have the smallest thermal inertia?

1. Slow-acting
2. Slow-blowing
3. Fast-acting
4. Time-delay

6-42. When possible a fuse should be operated at what percent of its rated value?

1. 75%
2. 85%
3. 95%
4. 100%

6-43. Refer to figure 11-4. Which of the following statements is NOT correct concerning a fuse with identification code F 02 C 400 V 10A S?

1. It is rated at 400 volts
2. It has a slow fail time
3. It is rated at 10 amps
4. It is silver plated

6-44. What is the most common class of fuse holder used by the Navy?

1. Indicating
2. Nonindicating
3. Splashproof
4. Post-type

6-45. What action, if any, should you take after a temporary surge of excessive current through a current limiter?

1. The current limiter must be replaced
2. The operator must check the circuit for proper operation
3. The current limiter must be reset by the operator before circuit operation continues
4. None; the circuit operates normally

6-46. Circuit breakers are rated in which of the following measurements?

1. Watts and amperes
2. Resistance and amperes
3. Watts and volts
4. Amperes and volts

Learning Objective: Identify the applications and outputs of external power sources. Recognize the physical differences of external power sources.

6-47. When operating in APU, you should NOT follow which of the following practices?

1. Be sure the proper number of wing walkers are used when moving aircraft with an APU
2. Never connect the APU to the aircraft with a hot line
3. Take care when moving an APU if the flightline is crowded
4. Place the power switches in the proper position before connecting an APU to an aircraft

6-48. Which of the following MEPPS must be towed?

1. NC-2A
2. NC-8A
3. NAC-10B
4. NC-12A

6-49. What is the output of a deckedge power system?

1. 400 Hz, 3-phase ac service voltage
2. 400 Hz, 1-phase ac service voltage
3. 60 Hz, 3-phase ac service voltage
4. 60 Hz, 1-phase ac service voltage

6-50. Which, if any, of the following air conditioning units has a cooling capacity of 19 tons?

1. NR-2B
2. NR-5C
3. NR-10
4. None of the above

Learning Objective: Recognize the basic requirements of a television system.

6-51. A basic television has how many elements?

1. 1
2. 2
3. 3
4. 4

6-52. Which of the following is NOT a pickup device?

1. Image orthicon
2. Microwave relay link
3. Vidicon
4. SEC tube

6-53. What type of scanning is used in television transmission?

1. Synchronized
2. Nonsynchronized
3. Horizontal
4. Vertical

6-54. Refer to figure 12-1. In the transmitter, what must be added to the electrical picture signal from the camera to make a composite video signal?

1. A sync operator signal
2. A signal from the pickup device
3. A receiver signal
4. A synchronizing signal

6-55. What total amount of time is required for one vertical scan of the picture in the United States?

1. 1/30 second
2. 1/60 second
3. 1/75 second
4. 1 second

6-56. What total number of scanning lines is used in commercial broadcast television for resolution of fine detail in the horizontal direction?

1. 100
2. 200
3. 300
4. 525

6-57. Of the following scanning methods, which one is the simplest?

1. Interlaced
2. Noninterlaced
3. Vertical
4. Horizontal

6-58. Interlaced scanning, rather than noninterlaced scanning, is used in most television systems for which of the following reasons?

1. Flicker is not increased
2. To reduce video bandwidth by a factor of two
3. Resolution is not reduced in interlaced scanning
4. All of the above

6-59. What is the horizontal scanning frequency of commercial broadcast and most closed circuit televisions?

1. 30 Hz
2. 60 Hz
3. 525 Hz
4. 15,750 Hz

6-60. The standard television signal consists of what total number of elements?

1. 1
2. 2
3. 3
4. 4

6-61. What is (a) the maximum percentage and (b) the minimum percentage of the maximum carrier voltage?

1. (a) 75 (b) 5
2. (a) 65 (b) 5
3. (a) 75 (b) 15
4. (a) 65 (b) 15

6-62. What is/are the purpose(s) of the kinescope blanking pulses?

1. To suppress the scanning beam during vertical retrace time
2. To suppress the scanning beam during horizontal retract time
3. Both 1 and 2 above
4. To suppress the scanning beam in the television camera

6-63. Refer to figure 12-3. The horizontal blanking pulses last for what maximum length of time?

1. 1/30 second
2. 1/60 second
3. 1/120 second
4. 1/15,750 second

6-64. Which, if any, of the following types of pulses provides a means of frequency discrimination?

1. Vertical sync
2. Horizontal sync
3. Serrated horizontal sync
4. None of the above

6-65. A television system which uses random interlace, no special sync pulses exhibits which, if any, of the following undesirable characteristics?

1. Circuit complexity
2. Long-range transmission use only
3. Insufficient resolution
4. None of the above

6-66. What is the video bandwidth of a slow-speed scan television system?

1. 500 Hz to 250 kHz
2. 750 kHz to 1 MHz
3. 1 MHz to 1000 MHz
4. 1000 MHz to 10,000 MHz

Learning Objective: Recognize the different types of camera tubes along with their operating characteristics and limitations.

6-67. Refer to figure 12-6. Which of the following components establishes a magnetic field along the axis of a vidicon tube?

1. Alignment coil
2. Focusing coil
3. Signal electrode
4. Accelerating anode

6-68. In the vidicon tube, the vertical and horizontal deflection coils get there excitation from

1. the cathode
2. grid 1
3. grid 2
4. the control unit

6-69. A plumbicon tube with a designation of 67423B has a color response for which of the following colors?

1. Red
2. Blue
3. Green
4. White

- Refer to figure 12-7 in answering items 6-70 and 6-71.

6-70. The tin dioxide contained in the faceplate is what type of semiconductor?

1. N-type
2. P-type
3. PNP-type
4. NPP type

6-71. Refer to figure 12-7(B). What type of function is formed?

1. PNP
2. NPN
3. PN
4. PIN

6-72. If three dynodes having a gain of three were used in the image orthicon tube, what would be the gain of the multiplier section?

1. 3
2. 9
3. 27
4. 81

6-73. Which of the following is NOT a use of the SEC tube?

1. Commercial television
2. Systems where fast speed is important
3. Systems where high internal amplification is important
4. Nightime military television systems

6-74. Which of the following statements describes the output circuit of a camera tube?

1. Its output must be as low as possible
2. It contains low resistance
3. It provides good gain at all frequencies
4. It provides more gain at some frequencies than at others

6-75. Refer to figure 12-10. Q1/Q2 serves as a peaker circuit for what reason?

1. To provide better amplification at lower frequencies
2. To provide better amplification at higher frequencies
3. To provide the same amplification at all frequencies
4. To form a video leveler

Assignment 7

TELEVISION

Text: Pages 12-12 through 12-49

Learning Objective: Recognize the basic operational parts of a television camera.

● In answering questions 7-1 through 7-4, refer to figure 12-11.

7-1. What type of camera tube is shown in the circuit?

1. Image orthicon
2. Vidicon
3. Plubmicon
4. SEC

7-2. What type of network, if any, is formed by C1 and R2?

1. Preamplifier
2. Clipper
3. Differentiator
4. None

7-3. In the circuit, transistors Q4, Q5, and Q6 are used for what purpose?

1. Video preamplifier
2. Emitter follower
3. Vidicon tube protection
4. Horizontal deflection

7-4. Closing switch S-1 will have what effect, if any, on the image of the camera?

1. It will cause a mirror image
2. The horizontal deflection yoke will not operate
3. The image will be inverted
4. None

7-5. Refer to figure 12-12. What information is contained in the Y signal?

1. Purple picture information
2. Brightness variations of the picture information
3. Chrominance information
4. Orange picture information

Learning Objective: Recognize the purpose, content, and methods of producing composite video.

7-6. The contents of the composite video contain all the information needed to produce

1. video from the camera
2. synchronizing pulses
3. blanking pulses
4. pictures

7-7. Refer to figure 12-13. Which, if any, of the following conditions exists during the time blanking pulses are transmitted?

1. Sync pulses are not being transmitted
2. Sync pulses are being transmitted
3. Video is transmitted
4. None of the above

7-8. When the amplitude level increases toward 75 percent, what perception, if any, is presented on the screen?

1. Blackest level on the screen
2. Whitest level on the screen
3. Grey level on the screen
4. None

7-9. Refer to figure 12-14. What is the duration of the horizontal blanking pulse?

1. .254 microsecond
2. 4.42 microseconds
3. 5.08 microseconds
4. 10.16 microseconds

7-10. The horizontal oscillator must be triggered during the vertical sweep pulse to prevent the horizontal oscillator from drifting out of control. What means is used to accomplish this?

1. The vertical pulse is serrated
2. The vertical pulse is not serrated
3. Equalizing pulses are added to the vertical pulse
4. Equalizing pulses are not added to the vertical pulse

7-11. Those pulses which are used before and after vertical pulses are known as

1. horizontal pulses
2. equalizing pulses
3. serrated vertical pulses
4. H pulses

Learning Objective: Recognize the purpose of control unit circuits.

7-12. What circuit is used to maintain phase lock in the horizontal and vertical sync signals?

1. A cathode follower
2. A sync generator
3. A blocking oscillator
4. A common master oscillator

● In answering questions 7-13 and 7-14, refer to figure 12-17.

7-13. The frequency and phase of the master oscillator signal is stabilized by what component?

1. Q9
2. Q2
3. Q3
4. Q4

7-14. What type of circuits are Q5, Q6, Q7, and Q8?

1. Four-stage amplifier network
2. Count-down circuits
3. Phase-detector network
4. Pulse counters

7-15. Refer to figure 12-18. What type of oscillator is formed by Q3 and the associated circuitry?

1. Hartley
2. Colpitts
3. A modified Armstrong
4. A modified Hartley

● In answering questions 7-16 and 7-17, refer to figure 12-19.

7-16. Normally, the transitor Q1 is in what state?

1. Conducting
2. Cut off
3. Controlled by the 60-Hz reference signal
4. Turned on by positive pulses

7-17. What is the purpose of C3?

1. It ensures that a smooth dc corrective voltage is applied to the resistive stage
2. It smoothes out the applied ac signal
3. It forms part of the RC time network
4. It functions as a filter capacitor

● In answering questions 7-18 and 7-19, refer to figure 12-21.

7-18. Which of the following components allow the transistor to conduct when the appropriate number of input pulses have been applied?

1. X6 and T2
2. R28 and R27
3. C17, R31, and R30
4. C17, R29, and R30

7-19. What is the count down of the frequency divider?

1. 5:1
2. 2:1
3. 3:1
4. 4:1

7-20. Before the blanking signal can be inserted to produce a composite video signal, what must be done to the raw video?

1. It must be amplified
2. It must be inductive coupled
3. It must be direct coupled
4. It must be clamped to a reference level

7-21. Refer to figure 12-23. What component in the circuit determines the blanking level?

1. R25
2. R31
3. R33
4. R39

7-22. Refer to figure 12-24. Through what component(s) is the sync added to the video signal?

1. R5 and R6
2. R33 and R34
3. R5 and R33
4. R6 and R34

Learning Objective: Identify television receiver components, and the operational characteristics of a television receiver.

7-23. What are the basic parts of a television tuner?

1. Video amplifier, oscillator, and mixer
2. RF amplifier, oscillator, and mixer
3. Video amplifier, mixer, and RF amplifier
4. Video detector, oscillator, and mixer

7-24. Which of the following is NOT an advantage of a FET over an ordinary transistor?

1. High-input impedance
2. Square law operation
3. The FET is a unipolar device
4. The FET has hole and electron flow simultaneously

7-25. Refer to figure 12-27. To what component of the MOSFET is the largest portion of the AGC voltage applied?

1. G1
2. G2
3. D
4. S

7-26. If the mixer is a nonlinear amplifier, the output will contain which of the following components?

1. The sum frequency only
2. The difference frequency only
3. The two original frequencies only
4. All of the above

7-27. Which of the following is NOT a characteristic of a varactor?

1. Varactors are solid-state devices with special doping
2. Varactors operate only with forward bias
3. The greater the bias on a varactor, the higher the resonant frequency
4. The varactor acts as a variable capacitor

7-28. What trap is widely used in color television receivers?

1. Series
2. Parallel
3. Bridged-T
4. Degenerative

7-29. Refer to figure 12-29(A). What type of trap is shown?

1. Parallel
2. Series
3. Bridged-T
4. Degenerative

7-30. Which of the following is a characteristic of the output of the bridged-T trap?

1. It is equal to the input
2. It is less than the input
3. It is 50 to 60 times greater than the undesired signal
4. It is 50 to 60 times greater than the desired signal

7-31. Refer to figure 12-30. Which of the following IF stages receives the AGC?

1. 1st IF
2. 2nd IF
3. 3rd IF

7-32. Which of the following statements describes the output of the video detectors?

1. The output of a video detector is positive
2. The output of a video detector is negative
3. The output may be either positive or negative, depending upon where the signal is applied to the picture tube

7-33. The frequency range of the video amplifier is from 30 Hz to

1. 1 kHz
2. 4 kHz
3. 1 MHz
4. 4 MHz

7-34. Refer to figure 12-35. The amount of charge on the capacitor (C) is determined by the

1. size of L
2. amount of B+ applied to the circuit
3. strength of the input signal
4. position of the wiper arm on P

7-35. When used between all stages in the video-amplifier section, what type of coupling, if any, eliminates the need of a dc restorer?

1. Direct
2. RC
3. RL
4. None

7-36. Refer to figure 12-36. What is the purpose of diode D2 in the circuit?

1. To achieve direct coupling
2. To develop AGC
3. To develop the sound signal
4. To compensate for nonlinearity in Q2

7-37. Refer to figure 12-37. At what point of the circuit is the sound IF removed?

1. The sound discriminator
2. The output of the converter
3. The second video stage
4. The 1st sound IF

7-38. Which of the following is an advantage of an intercarrier-sound system over a split-carrier sound system?

1. A narrower bandwidth
2. A greater number of audio stages
3. Fewer audio stages
4. A wider bandwidth

7-39. An ideal IC sound section contains what total number of terminals?

1. One
2. Five
3. Three
4. Ten

- In answering questions 7-40 and 7-41, refer to figure 12-39.

7-40. What is the required input to the quadrature dectector?

1. A sine wave
2. A square wave
3. A trapezoidal wave
4. A negative dc wave

7-41. What components are tuned to form a resonant circuit?

1. L1 and C1
2. C1 and L2
3. C2 and L1
4. C2 and L2

Learning Objective: Recognize the purposes of the operational parts of a picture tube.

7-42. What is the basic difference between color and monochrome picture tubes?

1. The type of biasing used
2. The phosphors coating the screen
3. The cathode circuit
4. The grid circuit

7-43. What shape is formed by the red, green, and blue dots on the screen of a color picture tube?

1. Circle
2. Square
3. Triangle
4. Rectangle

Learning Objective: Identify the basic purpose and operating characteristics of color circuits.

7-44. What is the difference, if any, between the tuners and amplifier stages of color television receivers as compared to monochrome receivers?

1. Narrower bandpass
2. One-stage amplifiers
3. Wider bandpass
4. None

- In answering questions 7-45 through 7-47, refer to figure 12-42.

7-45. What signal is used to drive the cathode of the CRT?

1. R-Y
2. G-Y
3. B-Y
4. Luminance

7-46. What is the purpose of the delay line in the video amplifier stage?

1. To delay the chrominance signals
2. To ensure the luminance and chrominance signals arrive at the same time
3. To ensure the chrominance signals arrive before the luminance signals
4. To ensure the luminance signals arrive before the chrominance signals

7-47. What circuits provide secondary control over the electron beam of each gun?

1. Video detector
2. Video amplifier
3. Convergence
4. Video output

7-48. Refer to figure 12-45. Q1 receives what total number of 3.58 MHz signals?

1. One
2. Two
3. Three
4. Four

7-49. Refer to figure 12-46. What is the input to the vertical deflection coils?

1. A square pulse
2. A negative-going pulse
3. A trapezoidal wave
4. A modified trapezoidal wave

7-50. Refer to figure 12-50. With respect to the width of each serration in the vertical pulse, the integrator has what type of time constant?

1. Short
2. Long
3. Equal
4. Cannot be determined by the figure

7-51. Refer to figure 12-51. If a square wave is the input, what type of circuit must be used to produce a sawtooth waveform at the output?

1. Resistive
2. Inductive-resistive
3. Inductive
4. Reactive

7-52. Refer to figure 12-52. What components determine the frequency of the vertical oscillator Q1?

1. C2, R3, and R5
2. C4, R7, and R8
3. C2, R3, and R2
4. C2, R4, and R5

7-53. Refer to figure 12-54. When D2 conducts more heavily than D1, what type of voltage is produced?

1. Negative-control
2. Positive-control
3. Equal
4. Opposite

Assignment 8

Avionics Maintenance

Text: Pages 13-1 through 13-30

Learning Objective: Recognize the characteristics of power supplies and other radar components.

8-1. In an unregulated power supply, low B+ is less than what minimum number of volts?

1. 100
2. 200
3. 300
4. 400

8-2. The type of circuitry selected for a power supply does NOT depend upon which of the following factors?

1. Voltage requirements
2. Regulation requirements
3. Weight limitations
4. Parts available

8-3. What is the most common type of power-supply test?

1. Resistance readings with the equipment turned off
2. Voltage readings with the equipment in operation
3. Current readings with the equipment in operation
4. Current readings with the equipment turned off

A. CRT

B. TRANSMITTER

C. PLATE VOLTAGE SUPPLY

D. SYNCHRONIZER

Figure 8A.

In answering questions 8-4 through 8-6, refer to figure 8A.

8-4. Which of the following components requires a high voltage source capable of delivering a large current for short intervals?

1. A
2. B
3. C
4. D

8-5. Which of the following components requires a high accelerating voltage which is easy to regulate?

1. A
2. B
3. C
4. D

8-6. Which of the following components requires a voltage source with good regulation and very little ripple?

1. A
2. B
3. C
4. D

8-7. Because of voltage requirements, power supplies are identifiable separate units.

8-8. Which of the following is NOT a cause of maintenance problems in radar equipment?

1. Poor solder joints
2. Proper electrical connections
3. Fused conducting strips
4. Mechanical vibration

Learning Objective: Identify the function, publications, and test equipment related to synchronizers.

8-9. The synchronizer is a single component used as a timing device in radar sets.

8-10. To which of the following publications should you refer to find synchronizer alignment procedures?

1. OPNAVINST 4790.2 (Series)
2. NA 01-00-509
3. MIM
4. RTM

8-11. Extensive use of what test equipment is required when making checks and alignments to a synchronizer?

1. VAST
2. SACE
3. DVDM
4. O-SCOPE

Learning Objective: Recognize the characteristics of and alignment procedures for radar indicators.

8-12. Radar indicator steering information is derived from the

1. target's speed
2. target's range
3. altitude line
4. antenna's position

8-13. If a presentation is not sharp at all positions on the indicator, you should adjust the focus and

1. contrast
2. astigmatism
3. intensity
4. brightness

8-14. If the B-trace sweep length is not correct, which of the following indications will be displayed INCORRECTLY?

1. Range
2. Azimuth
3. Elevation
4. Relative bearing

Learning Objective: Identify the factors relating to transmitter frequency and power measurements.

8-15. Transmitter operation is restricted to a certain range of frequencies for which of the following reasons?

1. Waveguide tuning adjustments cover only a limited range of frequencies
2. Interference could result if radars were operated in the same band
3. Both 1 and 2 above
4. Interference could result if radars were operated in different bands

8-16. Which of the following terms is used to describe a transmitter that has frequency shifting capabilities?

1. Fixed
2. Tunable
3. Interference-free
4. Jam-free

8-17. Which of the following components is used to detect absorbed power?

1. Resistor
2. Thermistor
3. Crystal
4. Transistor

8-18. Spectrum observation is accomplished by displaying the magnetron's output signal on a

1. frequency meter
2. power monitor
3. variable attenuator
4. synchroscope

8-19. Refer to figure 13-3. Which of the following lobes has the most power?

1. First side lobe--high side
2. Second side lobe
3. First side lobe--low side
4. Main

8-20. Which of the following is NOT a cause of a poor spectra?

1. A defective magnetron
2. A match in the RF section
3. An improper modulator pulse
4. A reflection from a nearby object

8-21. What does the pip in the center of the display indicate?

1. Transmitter frequency
2. Position of the transmitter dummy load
3. Test set oscillator frequency
4. Interference level

8-22. Which of the following is a characteristic of a low average power radar?

1. Long-range detection
2. Small transmitter
3. High cooling requirements
4. Wide pulsewidth

8-23. The most effective place to connect the pickup horn of a power meter is to the radar's

1. antenna
2. receiver
3. radome
4. directional coupler

8-24. When connecting a test set to measure average power, the frequency meter is off resonance to avoid

1. damaging the test set
2. a power loss
3. damage to the radar
4. reflected energy in the test set

8-25. Refer to figure 13-6. The output power of a radar system is 55 dBm. What is the radar's output power in watts?

1. 100
2. 200
3. 300
4. 400

Learning Objective: Recognize factors related to the sensitivity, frequency, maintenance tests, and maintenance procedures of radar receivers.

8-26. A 3 dB loss of receiver sensitivity equates to what dB loss in transmitter power?

1. 1
2. 6
3. 3
4. 12

8-27. Refer to figure 13-8. A radar set's performance is 20 dB less than optimum. The radar's performance equates to what percent of its original maximum range?

1. 10
2. 20
3. 30
4. 40

8-28. The sensitivity of the receiver determines the ability of radar to pick up

1. weak signals
2. strong signals
3. a target at close range
4. a target at long range

8-29. Which of the following is a satisfactory substitute for a noise-figure determination of a receiver?

1. Receiver frequency
2. Receiver bandwidth
3. STC
4. MDS

8-30. Before any measurements of receiver sensitivity can be made, the receiver must be accurately tuned to the

1. IF frequency
2. transmitter frequency
3. IAGC of the radar
4. AGC of the radar

8-31. Which of the following voltages should be checked when replacing a klystron?

1. Filament
2. Cathode
3. Reflector
4. Each of the above

8-32. Which of the following is NOT a characteristic of flange-mounted klystrons?

1. They may be mounted directly to a section of the mixer waveguide
2. They may be electrically insulated from the waveguide
3. They are easier to replace than the plug-in type
4. They are more difficult to replace than the plug-in type

8-33. Normally, there are what total number of methods that are used for measuring receiver sensitivity?

1. One
2. Two
3. Three
4. Four

8-34. Receiver response should be checked after any extensive repair to which of the following radar circuits?

1. AGC
2. IAGC
3. IF amplifier
4. STC

8-35. TR recovery time determines which of the following characteristics of radar operation?

1. Minimum range
2. Maximum range
3. MDS
4. Operating frequency

Learning Objective: Identify the purpose and methods of boresighting.

8-36. Which of the following components is/are NOT considered in boresighting procedures?

1. Antenna RF and optical axis
2. Optical sight unit
3. Launchers
4. Mk 4 gun pod

8-37. The AQ is normally required to perform adjustment to guns, launchers, and noncomputing sights.

8-38. Which, if any, of the following boresighting methods is used only with the director portion of the aircraft armament?

1. Full
2. Radar silence
3. Fast
4. None of the above

Learning Objective: Recognize the operating features and indications of the VAST and Mini-SACE test equipments.

8-39. During operation of the Mini-SACE test bench, the POL indication is displayed on the control panel. This is an indication of wrong polarity which causes the tape to react in which of the following ways?

1. Stop automatically
2. Proceed to the next sequential test
3. Restart automatically
4. Proceed to the next indicated test

8-40. A typical VAST test station is controlled by a

1. stimulus section
2. computer subsystem
3. measurement section
4. data transfer unit

8-41. The VAST test station has what maximum number of operating modes?

1. One
2. Two
3. Three
4. Four

8-42. What term is used to describe the second level of VAST fault detection?

1. Fault isolation
2. Self-check
3. Auto-check
4. Self-test

Learning Objective: Recognize the purpose, advantages, and equipment associated with reflectometry testing.

8-43. Which of the following is a use of the VAST system when used in the manual mode?

1. Debugging new programs
2. Performing self-check operations
3. Integrating new building blocks into the system
4. Each of the above

8-44. Reflectometry test sets are designed primarily to aid what level(s) of maintenance?

1. Organizational
2. Intermediate
3. Depot
4. Both 2 and 3 above

8-45. Which of the following terms describes a reflectometry test set currently in use?

1. Amplitude-domain
2. Frequency-domain
3. Pulse-domain
4. Waveform-domain

8-46. The signal inserted by a TDR is known as a/an

1. phase signal
2. reflected signal
3. impedance signal
4. incident signal

8-47. The TDR is capable of detecting faults in a wire or transmission line as close as what maximum number of inches apart?

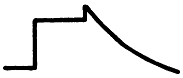
1. 1/8
2. 1/4
3. 1/2
4. 3/4

8-48. Refer to figure 13-17. If RL were greater than Z_o, what would be the reading on the oscilloscope?

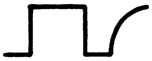
1. RL > 50
2. RL = 50
3. RL < 50
4. RL = 0

8-49. Refer to figure 13-18. Which of the following signals indicates a shunt RC condition?

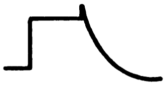
1.



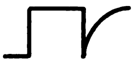
3.



2.



4.



8-50. What is the approximate impedance of a cable under test if the reflected mismatch is +0.06?

1. 50 ohms
2. 52 ohms
3. 53 ohms
4. 56 ohms

8-51. The output of the Tektronix 1502 TDR Tester is a step-signal with an approximate amplitude of

1. 125 mV
2. 225 mV
3. 325 mV
4. 525 mV

8-52. Which of the following controls on the Tektronix 1502 TDR Tester controls the brightness of the CRT display?

1. Focus
2. Gain
3. Intensity
4. Position/fine

Learning Objective: Recognize specific problems encountered when performing laser maintenance. Identify personnel safety.

8-53. Which of the following types of beams can cause severe eye damage when emitted from a laser?

1. A reflected beam
2. A direct beam
3. A reflected beam from a nonmirror surface
4. All of the above

8-54. A laser output of 25 joules is how many times more intense as the surface of the sun?

1. 1,000,000
2. 10,000,000
3. 25,000,000
4. 50,000,000

8-55. The beam from a laser does NOT obey which of the following laws.

1. Newton's
2. Inverse-square
3. $E=MC^2$

8-56. What happens to the size of the cornea of the eye as the distance of a focusing object increases?

1. The cornea becomes twice as large
2. The cornea decreases in size
3. The cornea remains the same size

8-57. Which of the following is NOT a laser safety procedure?

1. Use countdown procedures
2. One person is present when operating a laser, he/she must be qualified
3. Maintenance shops working on lasers should be closed areas
4. Wear protective devices when working with lasers

8-58. One device used in laser systems for additional safety is know as a/an

1. safety switch
2. time delay
3. count-down switch
4. interlock

8-59. The proper operating instructions for lazer pressurization kits may be found in

1. the system MIM
2. the 4790 series
3. the 509 manual
4. NAVEDTRA 10387-D

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6	☐	☐	☐	☐	_____	31	☐	☐	☐	☐	_____	56	☐	☐	☐	☐	_____
7	☐	☐	☐	☐	_____	32	☐	☐	☐	☐	_____	57	☐	☐	☐	☐	_____
8	☐	☐	☐	☐	_____	33	☐	☐	☐	☐	_____	58	☐	☐	☐	☐	_____
9	☐	☐	☐	☐	_____	34	☐	☐	☐	☐	_____	59	☐	☐	☐	☐	_____
10	☐	☐	☐	☐	_____	35	☐	☐	☐	☐	_____	60	☐	☐	☐	☐	_____
11	☐	☐	☐	☐	_____	36	☐	☐	☐	☐	_____	61	☐	☐	☐	☐	_____
12	☐	☐	☐	☐	_____	37	☐	☐	☐	☐	_____	62	☐	☐	☐	☐	_____
13	☐	☐	☐	☐	_____	38	☐	☐	☐	☐	_____	63	☐	☐	☐	☐	_____
14	☐	☐	☐	☐	_____	39	☐	☐	☐	☐	_____	64	☐	☐	☐	☐	_____
15	☐	☐	☐	☐	_____	40	☐	☐	☐	☐	_____	65	☐	☐	☐	☐	_____
16	☐	☐	☐	☐	_____	41	☐	☐	☐	☐	_____	66	☐	☐	☐	☐	_____
17	☐	☐	☐	☐	_____	42	☐	☐	☐	☐	_____	67	☐	☐	☐	☐	_____
18	☐	☐	☐	☐	_____	43	☐	☐	☐	☐	_____	68	☐	☐	☐	☐	_____
19	☐	☐	☐	☐	_____	44	☐	☐	☐	☐	_____	69	☐	☐	☐	☐	_____
20	☐	☐	☐	☐	_____	45	☐	☐	☐	☐	_____	70	☐	☐	☐	☐	_____
21	☐	☐	☐	☐	_____	46	☐	☐	☐	☐	_____	71	☐	☐	☐	☐	_____
22	☐	☐	☐	☐	_____	47	☐	☐	☐	☐	_____	72	☐	☐	☐	☐	_____
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PRINT OR TYPE

NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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PRINT OR TYPE

NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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PRINT OR TYPE

NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

NAME ______________________________ **ADDRESS** ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ **SOC. SEC. NO.** ______________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ______________ DATE MAILED ________

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PRINT OR TYPE

NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

SCORE ________

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PRINT OR TYPE

NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

NAME ______________________________ **ADDRESS** ______________________________
Last First Middle — Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ **SOC. SEC. NO.** ______________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ______________ DATE MAILED ________

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NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

ME ______________________ **ADDRESS** ______________________
Last First Middle Street/Ship/Unit/Division, etc.

City or FPO State Zip

NK/RATE ________ **SOC. SEC. NO.** ________________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

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INT OR TYPE

NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

ME ______________________ ADDRESS ______________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

NK/RATE ________ SOC. SEC. NO. ______________ DESIGNATOR ________ ASSIGNMENT NO. ________

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RINT OR TYPE

NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

AME ______________________ **ADDRESS** ______________________
Last First Middle Street/Ship/Unit/Division, etc.

City or FPO State Zip

ANK/RATE ________ **SOC. SEC. NO.** ______________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ______________ DATE MAILED ________

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NRCC AVIATION FIRE CONTROL TECHNICIAN 3 & 2, PART 2
NAVEDTRA 10387-D

AME ______________________ **ADDRESS** ______________________
Last First Middle Street/Ship/Unit/Division, etc.

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ANK/RATE ________ **SOC. SEC. NO.** ______________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

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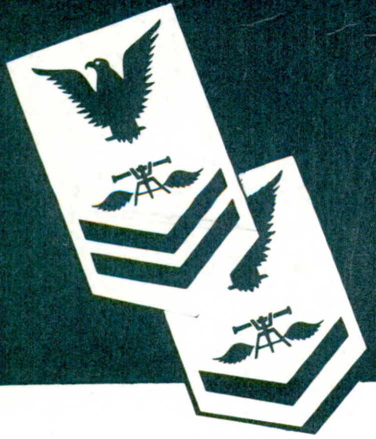

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